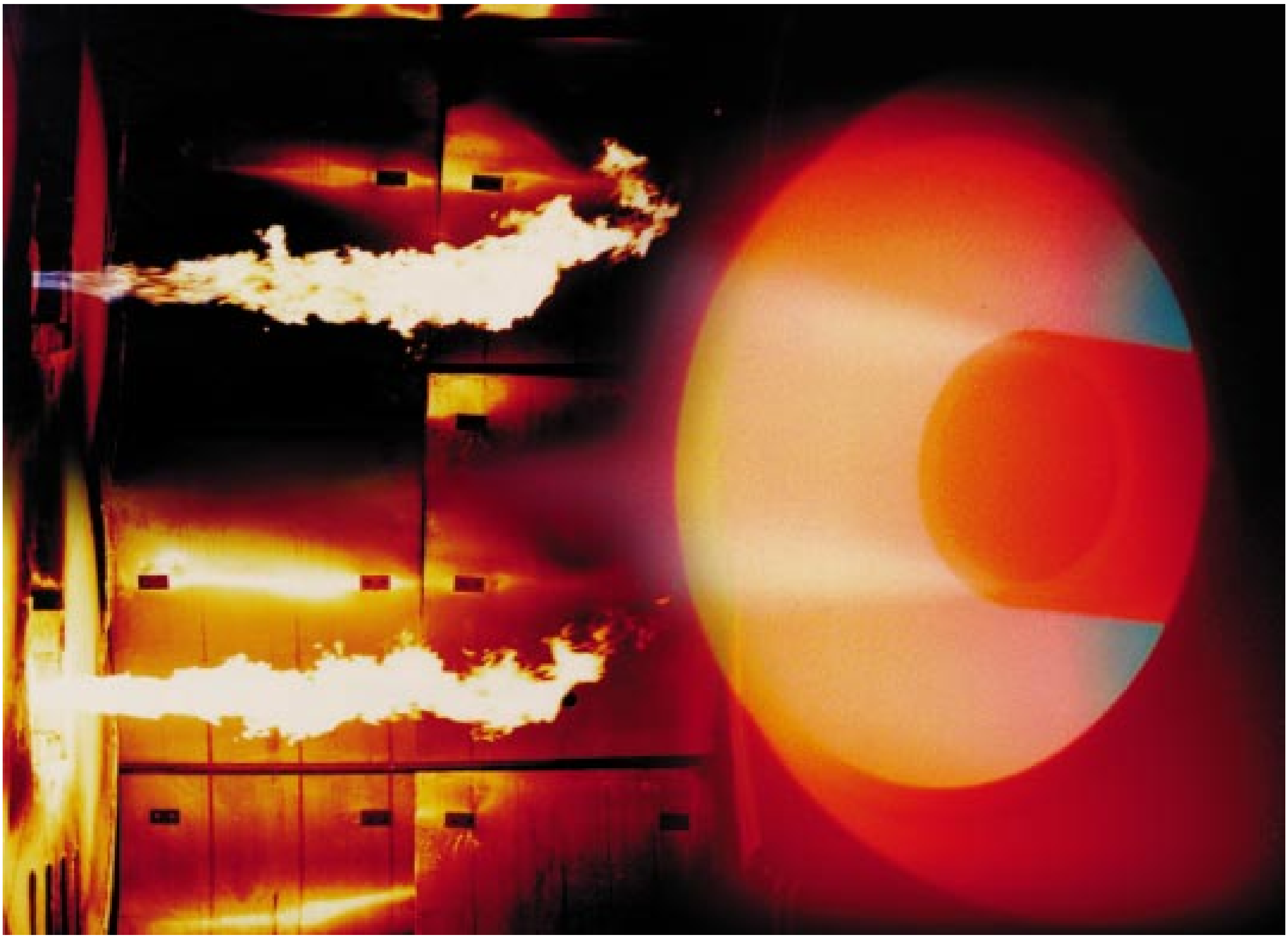
GOOD PRACTICE GUIDE 252

Burners and their controls



The Combustion Engineering Association

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

GOOD PRACTICE GUIDE 252

BURNERS AND THEIR CONTROLS

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Copies of these Guides may be obtained from:

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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

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BURNERS AND THEIR CONTROLS

1. INTRODUCTION

1.1 Background

There are an estimated 9,000 furnaces operating in the UK, many of which are equipped with fossil-fuel-fired burners. There are a wide variety of ***burner***[1] types and fuels in use. Advances in technology have resulted in the development of new ***combustion*** techniques and burner designs, and sophisticated controls. All can be readily applied to help any company that operates furnaces to reduce its operating costs, decrease pollutant emissions and increase productivity.

This Good Practice Guide is concerned only with burners used in industrial furnaces and ovens. Its purpose is to help furnace operators optimise the performance of their burner systems. Companies may simply wish to ensure that their existing burner system is operating effectively, and guidance on how to check this, along with typical problems and solutions, is given. Alternatively, the company may be seeking to improve the performance of an existing furnace through a general refurbishment, or planning the installation of a new furnace; in both cases the purchase of new burners may be considered. This Guide is structured in such a way as to provide information on the choices available and point the way forward to successful application of today's technology. The Guide does not cover burners fired with coal.

1.2 Other Guides in the Series

This Guide is part of a series aimed at industrial furnace users and is intended to give practical advice on a number of relevant subjects. Other Guides in the series include:

- Good Practice Guide 253, *Choosing, using and modifying furnaces*
- Good Practice Guide 254, *Furnace refractories and insulation*
- Good Practice Guide 255, *Electroheating in industry*

These Guides have been prepared under the Department of the Environment, Transport and the Regions' Energy Efficiency Best Practice Programme. They are available, free of charge to UK organisations, from the Energy Efficiency Enquiries Bureau (see Section 8.6 for details).

[1] Words that are in bold italics are explained in the glossary at the back of this Guide.

2. HOW TO USE THIS GUIDE

This Guide is structured so that it can be read cover to cover, or selectively by picking out information, as required, from the relevant sections. Fig 1 illustrates where the information may be found.

In addition, there are a number of applications guides that highlight specific information on burner selection and optimisation, fuel choice, and control selection.

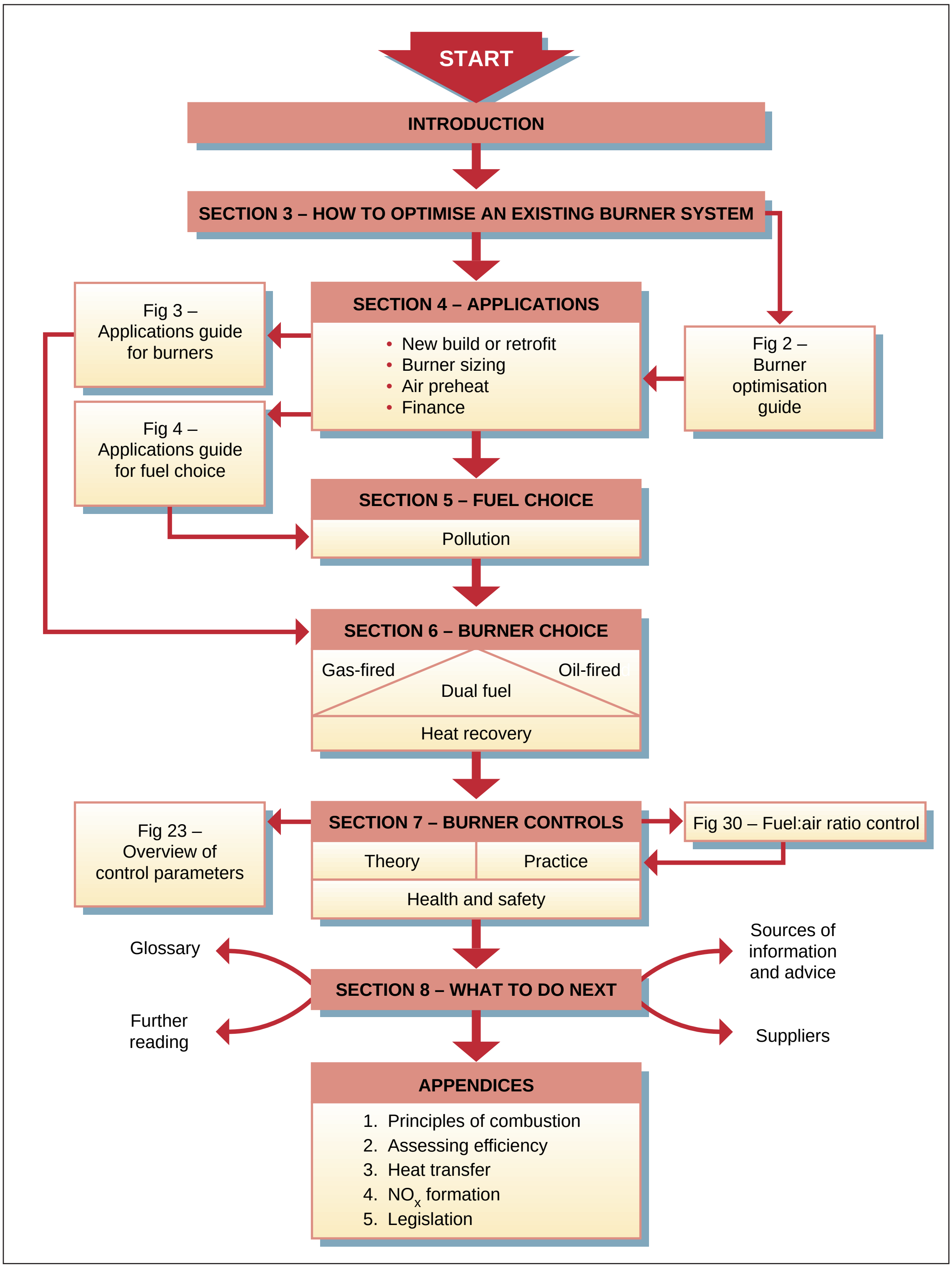

Fig 1 Information signposts

3. HOW TO OPTIMISE AN EXISTING BURNER AND CONTROL SYSTEM

The burner and control system of an existing furnace may well be operating below optimum efficiency, particularly if the furnace is old. However, this situation is not uncommon even for new furnaces. Tell-tale signs are poor product quality and high energy consumption, leading to a high reject rate and higher than necessary operating costs. If performance is suspect, careful analysis of historical data on energy consumption and production rate can often highlight specific problems. This type of monitoring is strongly recommended as part of routine good practice anyway, and should help to identify problems before they become too serious.

Fig 2 illustrates the steps to be taken in the burner optimisation process.

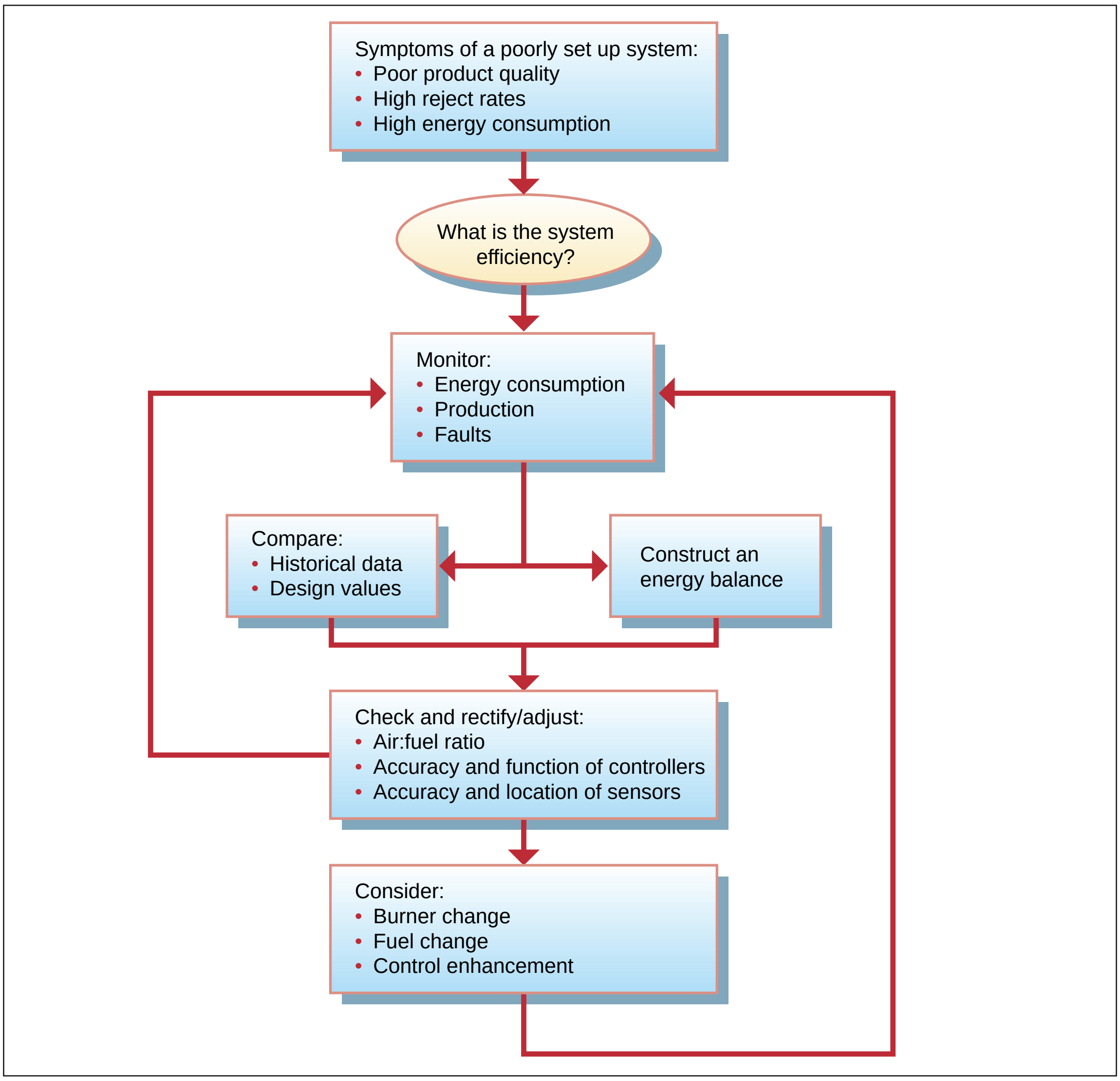

Fig 2 Burner optimisation guide

Compare the data collected[2] with that of other similar units and with the design specification. The burner manufacturer and/or the furnace constructor should be able to give guidance on typical values. It may be helpful to construct an energy balance of the furnace (see GPG 253 for details).

Controllers should be checked for function and accuracy, along with the accuracy and location of ***thermocouples,*** pressure sensors, and other control elements. Any deviations from expected values should be investigated and rectified.

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[2] The EEBPP is able to provide data on a number of furnaces through its Energy Consumption Guide. Please ring the Energy Helpline (Tel: 0541 542 541) for further information.

Problems with poor combustion and high energy consumption often stem from inadequate control of the burner's ***fuel:air ratio.*** This is discussed in greater detail in Appendix 1. An incorrect fuel:air ratio could be a result of air infiltration into the furnace as a result of poor pressure control, poor burner set-up (has the burner been dismantled recently?), poor mixing of fuel and air, or poor atomisation (in the case of oil-fired burners). Check for the following: damage to the burner nozzle and air register; damaged or worn components in the atomising mechanism used in oil-fired systems.

The fuel:air ratio is easy to check and should, in any case, be checked and adjusted on a regular basis. Appendix 2 gives further details on how to check combustion conditions by gas analysis. In some cases, permanent, *in situ* ratio controllers, generally known as ***oxygen trim controllers***, may be the best solution. These are covered in more detail, along with a financial analysis, in Section 7.

Careful analysis of these areas will indicate whether or not it is possible to improve the performance of an existing burner or burner system. Sometimes it may be more appropriate to replace the burners entirely, e.g. to install a gas-fired burner system in place of an oil-fired system, or to install a burner system using preheated ***combustion air.*** The following Section provides guidance on the options for ***retrofitting*** alternative burners to existing furnaces.

4. MAKING THE RIGHT CHOICE - IDENTIFYING THE REQUIREMENTS OF THE APPLICATION

Any burner or burner control project, whether it is a new furnace being constructed, the complete refurbishment of an existing furnace, or the retrofitting of new burners and/or controls to an otherwise serviceable furnace, needs careful consideration at the outset to maximise the benefits of the opportunity. This Section sets out some key aspects that should be considered before selection of the burner(s) and controls. Figs 3 to 7 can be used as a short-cut to the required information.

4.1 What is the Application?

Before selecting a burner and control system it is essential to consider the intended application. There are many types of burner available, firing a variety of fuels or fuel combinations. However, not all of these may be suitable for a particular application.

For instance: is the application a batch or continuous process? Obviously, this will affect the shape of the furnace, and has implications for the number, output and positioning of burners.

Another key question is: which method of heat transfer best suits the process?

- Applications requiring high-temperature and uniform heating, e.g. the melting and holding of metal or glass, would be best suited to a furnace and burner system promoting high levels of radiative heat transfer. Similarly, high-output processes requiring a large amount of heat to be transferred to the stock in a very limited time (e.g. a reheat furnace in a rolling mill) are best served by a radiative system. Typically, this would involve the use of a long, highly ***luminous flame,*** which could be achieved by oil firing, gas firing using a delayed mixing strategy, or possibly oxy-enrichment. An alternative might be to produce the radiant heat indirectly by using a flat-flame burner to scrub the walls of the furnace, causing them to heat up and radiate back onto the stock.

- Processes requiring deep penetration of the heat into the stock, which may be densely packed, or where there is an element of mass transfer involved (e.g. firing of bricks or ceramics, or drying operations) are best served by a convective heat transfer method. Here, a very turbulent furnace atmosphere is required. This could be achieved by the use of either high-velocity burners or, possibly, a pulse-firing method in which the burner(s) is fired cyclically at full power, thereby creating a very agitated atmosphere within the furnace. Rapid heaters also make use of high-velocity burners to heat stock by convective heat transfer.

Heat transfer is discussed in more detail in Appendix 3.

Furnace atmosphere is another important consideration. Where the presence of combustion gases within the furnace atmosphere might damage the stock, then an indirect firing method such as a ***radiant tube*** burner will be required. Nonetheless, where direct firing is used, the combustion gases can be manipulated by varying the amount of oxygen (in combustion air) supplied to the flame to create either a reducing or oxidising atmosphere within the furnace. Where a reducing atmosphere is required, however, the use of oil as fuel will be ruled out as it is very difficult to burn oil cleanly without a high level of ***excess air.***

All of these, and other aspects, must be considered carefully before a burner system can be selected.

CAUTION!

Failing to carry out the necessary technical and financial analyses can have disastrous consequences, e.g. increasing the operating costs, possibly harming product quality, and limiting production. Burner and furnace manufacturers, consultants, research organisations, trade associations, and the Energy Helpline (0541 542 541) are all available to offer help and advice. Time and care taken at this stage will help to ensure the success of the project.

The applications guide in Fig 3 has been developed to help identify the appropriate application category before selecting the correct burner type.

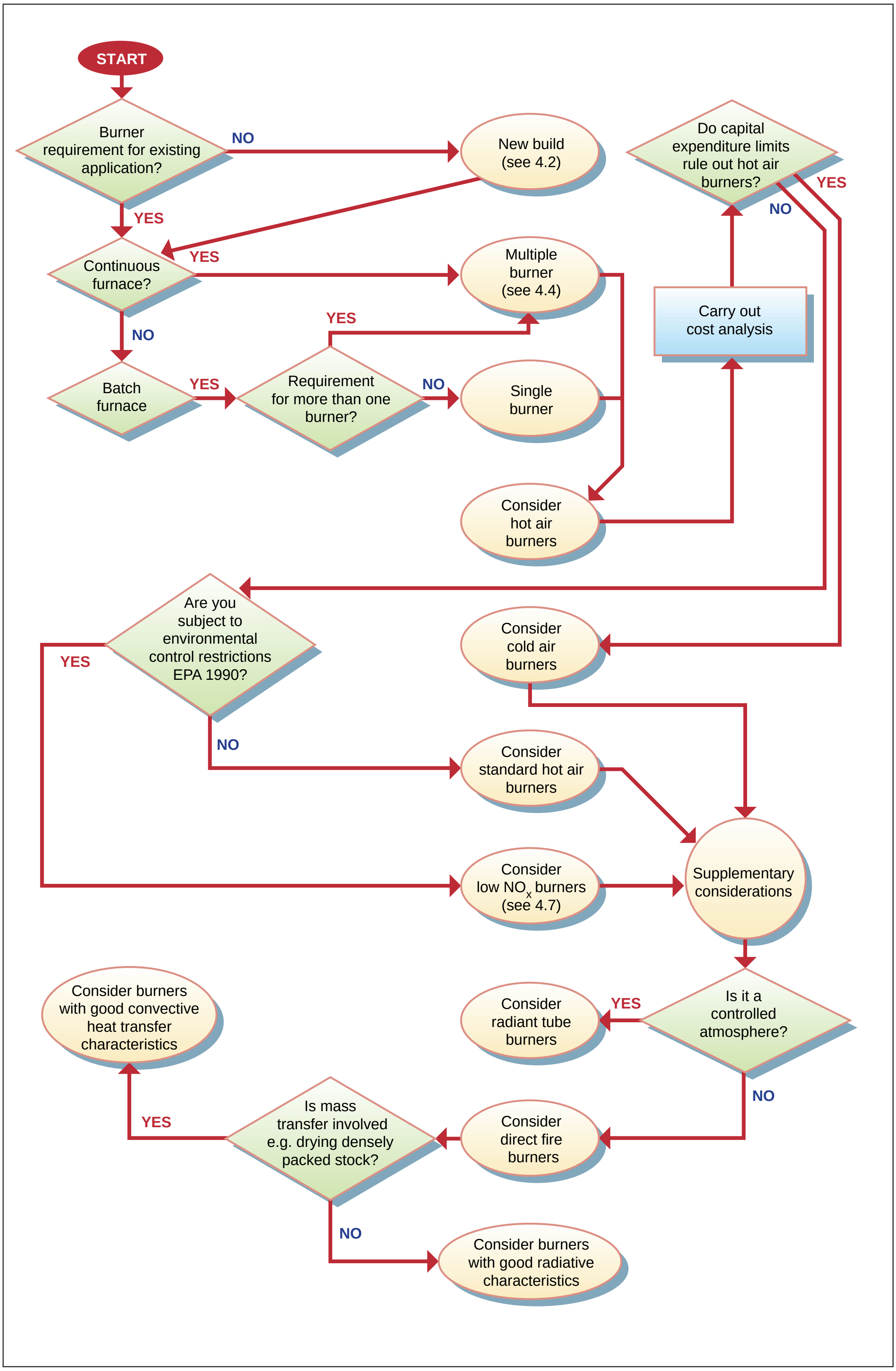


Fig 3 Applications guide for burners

4.2 New Build, Refurbishment and Retrofit

A new furnace presents an ideal opportunity to design a combustion system that is matched exactly to the application, and is efficient and environmentally clean. When planning a new furnace it is advisable to consider the potential effects of any future changes, e.g. a change in product or working practices, and design the system with flexibility in mind. In the majority of cases, the specification of the furnace will be the leading factor in the choice of burner. The companion Guide in this series - Good Practice Guide 253, *Choosing, using and modifying furnaces* - gives further information on this area.

Similarly, the general refurbishment of a furnace, e.g. to improve efficiency or meet new emissions limits, presents a rare opportunity to upgrade or replace existing burners and controls at marginal cost. Careful planning will ensure the opportunity is not wasted.

Most modern burner and control systems discussed in this Guide may be readily retrofitted with only minor alterations to the structure of the furnace, and most burner and furnace manufacturers will provide such a service.

In all cases, careful analysis of the financial case for investment is essential. Although high-efficiency hot-air burners are more expensive than conventional cold-air burners, the running costs will be significantly less, and short paybacks are common. Also, although the extra cost of installing a low-emission combustion system may be insignificant in the overall cost of a furnace installation, the costs of a possible prosecution and forced installation for breaching emissions limits will be significantly more.

4.3 Fuel Choice

The fuel selected has a strong influence on: the effectiveness of the combustion and heat transfer process; pollutant emissions; and the overall operating and maintenance costs of the furnace system as a whole. Fuel choice is therefore a prime consideration when planning a new furnace or the retrofitting of an existing furnace, or examining existing procedures in the course of a financial or environmental review. The subject of fuel choice and pollution is covered more fully in Section 5.

The applications guide in Fig 4, overleaf, has been devised as an overview to selecting the most appropriate fuel.

4.4 Size, Number and Positioning of Burners

The type of process and furnace design will have a strong influence on the number, type and positioning of burners. For example, a small batch furnace may require only a single burner (or pair of burners in the case of a regenerative firing system) which would provide adequate distribution of heat through the stock. However, a continuous furnace with several zones would require an array of burners, possibly grouped and controlled by zone in order to achieve the uniformity of stock heating required. Burners should be sited to ensure sufficient dwell time before the hot gases are exhausted. Mathematical and physical modelling techniques can be used to determine the optimum size and position of burners before furnace construction or refurbishment projects are undertaken. Burner and furnace manufacturers and suppliers, as well as fuel supply companies and research bodies, can generally help with the construction of models.

4.5 Mathematical and Physical Modelling

Prior to manufacture or construction, modelling techniques are frequently used by burner and furnace designers to predict the performance of systems. There are several advantages to this approach, not least of which is avoiding the expense of building prototype plant to investigate the effects of varying design parameters. Modelling techniques can also be put to good use for troubleshooting existing furnace or burner systems, or when planning a refurbishment or retrofit project.

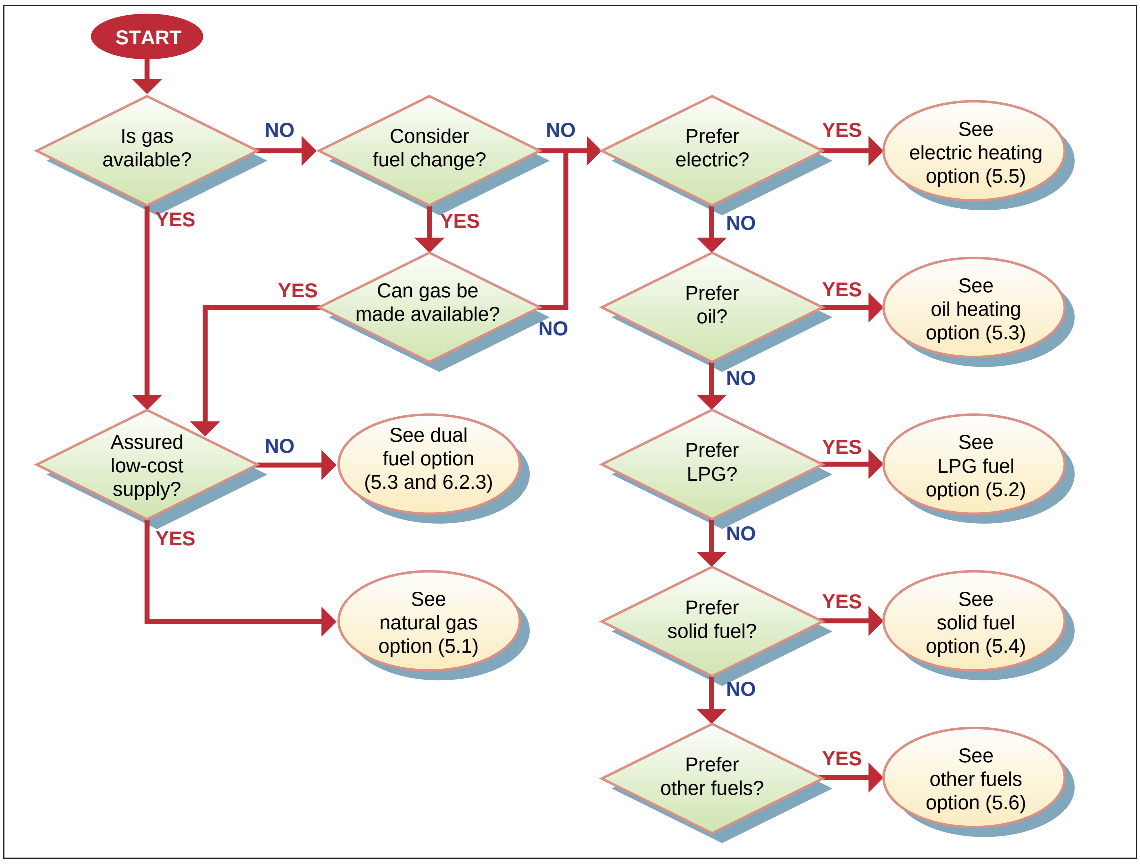


Fig 4 Applications guide for fuel choice

4.5.1 *Mathematical modelling*

Mathematical modelling may be used to investigate: flame temperature and flow profiles; furnace temperature profiles; stock heating rates; the thermal requirements of furnaces, e.g. zoning arrangements and burner ratings. One modern practice is to use a personal computer running a commercially available computational fluid dynamics (CFD) software package. This enables the complex numerical models developed to analyse flow, gas mixing patterns, combustion characteristics, and heat transfer rates to be evaluated. Fig 5 shows the output of a commercially available mathematical model used to predict flame temperatures from a low-NO_x burner[3].

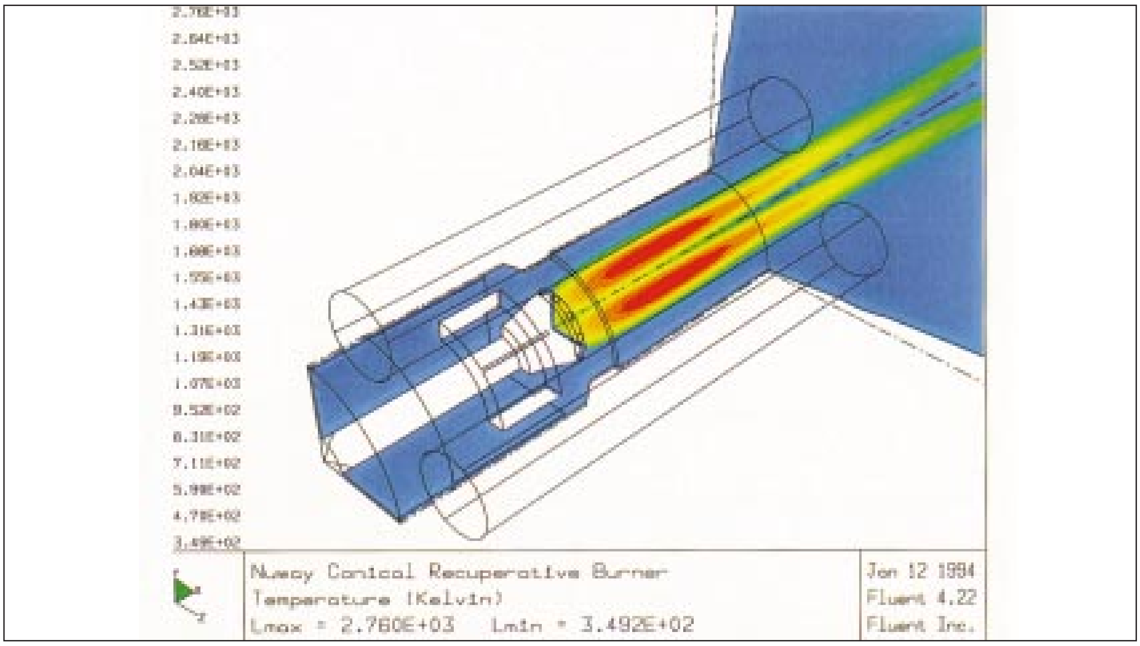


Fig 5 Mathematical model of burner flame/temperature characteristics

[3] See Section 4.7 for further details on low-NO_x burners.

There are several software packages commercially available; however, the costs of purchasing and learning a CFD package may not be worthwhile for individual or one-off projects. A number of organisations offer mathematical modelling consultancy services on a contract basis. This might make better sense, particularly for smaller companies. Details of such organisations can be found in Section 8.7. Likely consultancy costs range from £5,000 to £15,000 for a single burner system, depending on the complexity of the problem and the time involved.

Example

One company decided to try and boost the output of its steel reheating furnace by adding an extra zone. In practice, the modification actually *downgraded* the performance of the furnace. In the end the company had to resort to mathematical modelling of the furnace to establish the cause of the problem and then carry out further modifications. If modelling had been carried out at the beginning of the project this costly mistake might have been avoided.

4.5.2 *Physical Modelling*

Physical modelling is a cheaper approach, and could be carried out, relatively easily, in-house. This technique, also known as cold modelling, involves the construction of a small-scale model of the furnace or system to provide information on flow patterns, gas/gas interactions, rates of gas movement, gas mixing characteristics, convective heat transfer and pressure fluctuations. Models may be two- or three-dimensional and are typically constructed from clear perspex to aid visibility. They may use either cold air or water to represent the flow of hot combustion gases. ***Pitot static*** tubes are used to measure flow rates and velocities; tracers, such as carbon dioxide (CO_2), or polystyrene balls for air systems and dyes for water systems, are used to visualise flow and mixing patterns (see Fig 6). Again, several organisations offer physical modelling services on a contract basis (see Section 8.7).

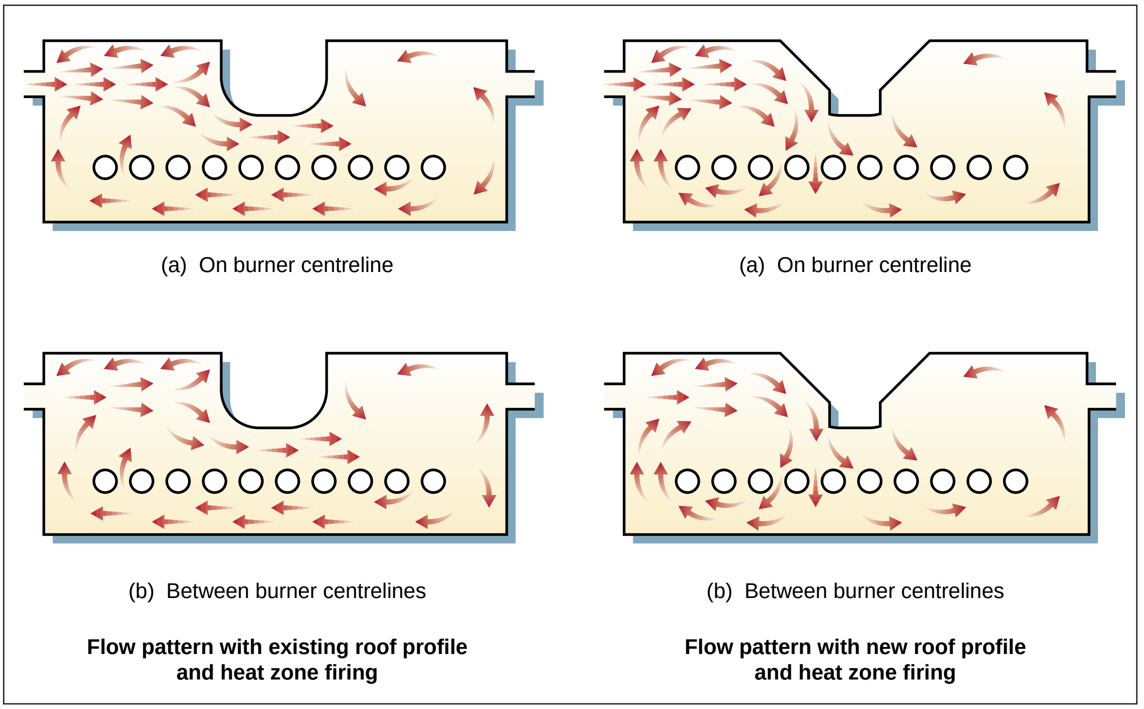


Fig 6 Physical model study of a continuous tube reheating furnace

4.6 Combustion Air Preheat as a Means of Increasing Efficiency

Conventional burners are designed to operate with cold air. They are generally simple, rugged and reliable, and of reasonable efficiency. However, opportunities exist for dramatically improving the efficiency of a combustion system by as much as 50% by preheating the combustion air. Air ***preheat*** is usually achieved by recovering the waste heat from the furnace exhaust gases that would otherwise be discharged to atmosphere. The exhaust gases and cold air are passed through a heat exchanger and the resulting heated air is fed to the burner as combustion air. The outcome is higher flame temperatures and significantly improved efficiency. Higher flame temperature can also be beneficial in increasing the output of the furnace. Many companies have used this approach, primarily to boost furnace output, but with the added benefit of lower specific fuel consumption.

CAUTION!

Combustion air preheat achieves higher flame temperatures but can also result in increased production of NO_x. When selecting a hot-air burner for a new furnace or retrofit project, always ensure that a low-NO_x design is a high priority.

4.7 Low-NO_x Burners

Various oxides of nitrogen, collectively termed NO_x, are formed during the combustion process. NO_x emissions are blamed for a number of environmental problems including acid rain and photochemical smog. Further details on the mechanisms of NO_x formation and methods of control are given in Appendix 4 and covered in a number of other publications (see Section 8.5).

With the increasing need to minimise air pollution, brought about by public concern, and now legislation, manufacturers have turned their efforts to developing high-efficiency, low-pollution variants of their burner ranges. The use of preheated combustion air brings further problems as the higher flame temperatures achieved cause even higher emissions of NO_x.

Burner manufacturers now produce a range of ***low-NO_x burners,*** for both cold- and hot-air firing. The burners incorporate several special features, usually including carefully staged combustion and partial fuel ***premix,*** and have been shown to successfully reduce NO_x emissions from furnaces. Hot-air burners are available in both self-recuperative and regenerative firing versions.

The purchase cost of a low-NO_x burner may be slightly higher than that of a standard self-recuperative burner. However, the remainder of the firing system will be identical to that of the standard burner, so the overall premium will not be as great. Low-NO_x designs are likely to take an increasingly large share of the new build and refurbishment market as emissions limits are tightened.

4.8 Financial Considerations

As with most potential projects, there will usually be several technically viable schemes. The aim is to select the one which will provide the most cost-effective solution. The choice of burner and control systems for both new furnaces and retrofitting of existing furnaces should, like all capital projects, be subject to careful financial appraisal to determine the most economic course of action. Good Practice Guide 69, *Investment appraisal for industrial energy efficiency*, contains details of the financial appraisal techniques commonly used in investment decisions. The aim of this Guide, however, is to provide the technical detail necessary for selection and specification of the most appropriate equipment. Where necessary, worked examples and case studies are used to illustrate appropriate financial appraisal techniques.

Other considerations include third party finance possibilities, e.g. supplier leasing or phased payment options, or shared savings contracts. These opportunities should be explored with any potential supplier. Grant-assistance may be available for energy efficiency and environmental improvement projects, and this should be fully explored with both UK Government and European Union sources. For further details, contact the Energy Helpline on 0541 542 541.

4.9 Burner Specification

As indicated in this Guide, burner specification is a complex issue and rarely tackled in isolation. Normal practice is to consult burner manufacturers and suppliers to ensure the technical requirements are satisfied exactly. The initial purchase price of the equipment on offer is a major consideration in most purchases, but should not be the only one. Subsequent operation and maintenance costs are also critical and will exceed the initial purchase price several times over during the lifetime of the burner. Therefore, the cheapest is not always the best choice.

A reputable burner supplier will want to know precise details of the application before making a recommendation. The form presented in Fig 7 overleaf gives an idea of the type of information likely to be requested. Try to assemble the information beforehand to make the process as smooth as possible. The form can be copied and used directly, or suppliers may have their own versions.

A word of caution: there is a distinction between burner manufacturers and suppliers. Some suppliers may buy burners directly from a manufacturer in bulk and sell them on to customers at a small profit margin. However, such suppliers may not be prepared, or able, to provide an effective after-sales service, including essential spares and maintenance. There could be difficulties if a serious problem arises with the equipment. An unhelpful supplier may point to the manufacturer who, understandably, might not want to be involved. It is essential to know exactly what is being bought and from whom.

INFORMATION-GATHERING SHEET

Company name . . . .
Address . . . .
. . . .
Contact name . . . . Position. . . . .
Telephone . . . . Fax . . . . Other. . . . .
Type of process (include a diagram if possible) . . . .
Furnace type, manufacturer and date . . . .
Please include an accurate diagram showing main dimensions, wall thickness, construction materials, roof profile, burner positions/centres/height above hearth, flue/exhaust positions.
How many burners required/exist now? . . . .
What is the individual capacity of the existing burners? . . . .
Type of product to be heated . . . .
Size of stock to be heated, all sizes - cross-sections/length. . . . .
Throughput - pieces of each size/hour, tonnage/hour . . . .
Are there any regular delays in furnace operations? . . . .
Maximum and minimum throughput - tonnage/hour . . . .
Maximum hearth loading - kg stock/hour/m^2 hearth. . . . .
Desired stock temperatures . . . .
Typical operating hours/day or week . . . .
What is the fuel/fuel specification? . . . .
What is the existing (if applicable) total fuel consumption for the furnace? . . . .
What is the specific fuel consumption (units/tonne) -
production and overall (inc. start-up)? . . . .
Fuel temperature/pressure available . . . .
Unit cost of fuel(s) used. . . . .
Combustion air supply - volume/pressure/temperature . . . .
Is combustion air preheat required/used - how and at what temperature? . . . .
What type of exhaust/flue system is required/used? . . . .
What type of combustion control system is required/exists?. . . . .
How many control zones required/exist? . . . .
Where are/will the thermocouples (be) located?. . . . .
Does the furnace have pressure control? . . . .
What type of burner ignition/start-up sequence is used/required?. . . . .
What power supplies are available to the instrumentation, safety equipment, fans, pumps, etc.? . . . .
What are the existing combustion conditions (CO, CO_2, O_2, NO_x, etc.)? . . . .
. . . .
What are the overall operating conditions - clean/dirty?. . . . .
Any particular safety or environmental issues:. . . . .
Is your site/process subject to an EPA Part ‘A’ (Environment Agency) or Part ‘B’ (Local Authority) regulated process? . . . .
Are there any particular problems experienced now with the existing furnace, burners, safety system or controls?. . . . .
Additional information. . . . .

Fig 7 Burner and control system specification

5. FUEL CHOICE

As previously mentioned, fuel choice is one of the prime aspects to be considered *before* a burner is selected. Important factors include:

- price, tariff choice;
- availability;
- ease of handling;
- pollution potential.

The main characteristics of the commonly available fuels are presented below.

5.1 Natural Gas

Natural gas is a premium quality, low-cost fuel that is easy to control and relatively low in emissions. Natural-gas burners are cheaper to maintain and the use of natural gas may also increase refractory life. As a result, gas is the first choice in many burner and furnace applications. However, natural gas is not yet universally available in the UK, and the capital cost entailed in extending or upgrading the local gas distribution network may rule out natural-gas firing for some potential users.

5.2 Liquefied Petroleum Gases (LPG)

Liquefied petroleum gases (LPG) comprise a mixture of propane (C_3H_8) and butane (C_4H_{10}), and are manufactured during the refining of crude oil. Because they are gaseous at normal temperature and pressure, they are stored under pressure as liquids. LPG is normally supplied by road tanker and must be stored in a pressure vessel on site. Propane and butane are fuels of high ***calorific value*** and are capable of delivering high rates of heat input. A major advantage of LPG is that, like natural gas, it is a relatively clean-burning, low-emission fuel. However, LPG fuels can contain unsaturated hydrocarbons which can lead to soot formation, thus necessitating specially-designed burners. ***Turndown*** may be limited and maintenance costs slightly increased. LPG tends to be more expensive than most other fuels, and there are the additional capital and ongoing costs of installing and maintaining a bulk storage tank to be considered. The tank would also be subject to regular testing and inspection under the Pressure Vessel Regulations.

5.3 Fuel Oils

Fuel oils are widely available and relatively low-cost. Their handling, control, and use are less straightforward than for natural gas, and pollutant emissions are likely to be higher due to the presence of sulphur and nitrogen compounds in the oil. In addition, smokeless combustion requires larger amounts of excess air to be used, which can make it difficult to obtain a reducing atmosphere in the furnace if required. Fuel-oil firing does, however, have advantages in terms of improved radiative heat transfer. This is due to the higher luminosity and emissivity of the flames produced when oils are burnt.

Fuel oils are classified according to their viscosity, or ‘weight’, and graded according to increasing viscosity, i.e. from gas oil, light fuel oil, and medium fuel oil, to heavy or residual fuel oil. The heavier grades must be stored above room temperature, and require a slightly higher temperature for pumping and burning. Even gas-oil pipe runs may require trace heating to avoid thickening of the oil and reduction of flow to the burner in winter conditions.

Where natural gas is unavailable, fuel oils are generally the next best choice as they are less expensive than LPG. Lighter fuel oils contain less sulphur and are easier to handle and burn than heavier fuel oils, although their purchase cost is higher. Where the supply of natural gas cannot be guaranteed, or an ***interruptible tariff*** has been selected for cost reasons, ***dual-fuel burners,*** which enable the user to switch between fuels as required, are available.

When considering the use of liquid fuels, remember that on-site storage and handling facilities must be provided, and that this can add considerably to the capital cost of an installation.

5.4 Solid Fuel

Solid-fuel firing, either by chain grate stoker, fluidised bed, or as pulverised fuel, is widely used in boiler plant for power generation purposes. However, its use in furnace applications in the UK is rare, although there are applications in quarrying and the metallurgical industries. Coal firing may cause slagging and fouling deposits on heat exchanger surfaces, due to a combination of the ash in the coal and the relatively high temperatures involved. Coal firing also produces a range of pollutants, but these can be combated by the use of appropriate clean combustion technology. Considerable development work has been undertaken in recent years to produce low-NO_x burners for pulverised coal. Solid-fuel firing is not considered in this Guide.

5.5 Electricity

For heating purposes, the use of electricity is an alternative to fossil-fuel firing. Electricity may be selected for reasons relating to emissions or for other requirements; however, operating costs are often likely to be higher due to the significantly higher unit cost of electricity compared to fossil fuels (although maintenance costs are generally lower). On a global scale, pollution emissions can be higher due to inefficiencies in the power generation process. A companion Guide in this series - Good Practice Guide 255, *Electroheating in industry* - covers the application of electroheating techniques in detail. In addition, Good Practice Guide 253, *Choosing, using and modifying furnaces*, shows how to balance the appraisal.

5.6 Alternative Fuels

The availability of alternative fuels, e.g. coke oven gas, biogas or waste oils, may present further opportunities for cost savings, although the implications in terms of emissions and heat transfer capability will need to be examined on an individual basis.

The key properties of common fuels are summarised in Table 1.

Table 1 Properties of common industrial fuels

Fuel	Gross calorific value*	Net calorific value	Pollution potential (see Table 3 also)	Comparative costs**		Delivery method	Storage facilities required
				(£/t)	(£/GJ)		
Natural gas	38.6 MJ/m^3	34.8 MJ/m^3	Low	113.40	1.2- 2.5	Pipe	No
LPG	93.1 MJ/m^3	86.1 MJ/m^3	Low	196.60	2.1	Batch	Yes
Light fuel oil	45.4 MJ/kg	42.4 MJ/kg	Medium	169.20	3.6- 4.0	Batch	Yes
Heavy fuel oil	42.9 MJ/kg	40.5 MJ/kg	High	97.60	2.1- 2.5	Batch	Yes
Coal	30.4 MJ/kg	29.4 MJ/kg	High	35.20	1.2- 2.0	Batch	Yes

* Gross calorific value includes the heat liberated when water vapour produced condenses to liquid at room temperature.

** Due to the movement of relative fuel prices, it is strongly recommended that the prices be checked before undertaking any detailed study.

5.7 Fuel Cost Guide

There is a wide variance in fuel costs. Factors to be considered include: the quality of the fuel; the quantity purchased; and the additional capital costs involved in using a particular fuel, e.g. the costs associated with the provision of on-site storage and handling equipment (e.g. for fuel oil or LPG) or pollution abatement equipment.

Table 2 and the attached examples have been developed to enable easy comparison of the likely purchase costs of various fuels.

Table 2 Fuel cost comparison table

Fuel type	Annual consum-ption	Units	Conver-sion factor to GJ	Consum-ption (GJ)	Cost (£/unit)	Cost (£/GJ)	Annual running cost (£)	Annual production	Units	SEC* (GJ/unit)	SEC (£/unit)
				(1) X (2)		(4)/(2)	(3) X (5)			(3)/(7)	(6)/(7)
	(1)		**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Natural gas		kWh	0.0036								
LPG		tonnes	50								
Gas oil		litres	54.05								
Light fuel oil		litres	46.77								
Medium fuel oil		litres	45.37								
Heavy fuel oil		litres	44.69								
Electricity		kWh	0.0036								

Example

Natural gas	16,138,055	kWh	0.0036	58,097	0.0069	1.92	111,546	35,000	tonnes	1.66	3.19
Heavy fuel oil	1,300,000	litres	44.69	58,097	0.1	2.24	130,000	35,000	tonnes	1.66	3.71

* ***Specific energy consumption***

In this example, two fuels used in a reheating furnace are compared. Results indicate that, for the same fuel consumption and production output, natural gas would be the preferred option in terms of running costs.

5.8 Oxygen Enrichment and Oxy-fuel Firing

Oxygen (O_2) enrichment, and oxy-fuel firing, refer to the combustion of fuel with pure or near-pure oxygen, either in addition to, or as a direct replacement for, air. The practices are not widely used at the moment, chiefly due to the high cost of commercially available oxygen (roughly twice the cost of fuel). However, the availability of packaged equipment for on-site generation of high-purity oxygen may increase the uptake of this technology.

Oxygen enrichment and oxy-fuel firing have the following advantages:

- the ability to achieve high flame temperatures, even with fuels of low calorific value;
- improved heat transfer, as a result of the higher flame temperatures;
- minimisation of waste gas volumes, and consequent reduction in capital cost of exhaust and stack installations and lower waste gas heat losses;
- increased flexibility in control of the furnace atmosphere;
- the possibility of reduced NO_x emission levels, under certain circumstances;
- increased flexibility of furnace operation, e.g. higher output.

In some circumstances, therefore, either oxygen enrichment or oxy-fuel burners may be used as a lower-cost measure to upgrade the performance of an existing furnace, without having to resort to costly structural modifications or even replacement.

Although the term oxy-fuel firing implies combustion in pure oxygen without ‘normal’ air, and hence nitrogen, in practice this is not so. Similar considerations apply to oxygen enrichment where due to higher flame temperature, NO_x formation may occur because of air already in the furnace environment. The result is that any nitrogen in the air is converted into NO_x because of the very high flame temperatures reached. This can mean an actual increase in NO_x emissions, rather than the reverse. Therefore, commercially-available oxy-fuel burners incorporate features designed to achieve acceptably low-NO_x emissions. Oxy-fuel burners are covered in Section 6 of this Guide.

Note: At the time of writing, UK legislation stipulates NO_x emissions limits in terms of concentration, i.e. mg/m^3. With oxy-fuel firing, flue gas volumes are actually reduced due to the absence of molecular nitrogen in the ***flue gases.*** *As a result, concentrations of NO_x may appear higher, whereas, if compared on a mass basis, they are actually lower. Therefore, in the absence of an appropriate ‘official’ correction factor, special dispensation may be required from the regulating bodies (see Appendix 4) to operate oxy-fuel-fired systems.*

5.9 Pollution

Pollution from combustion processes is inevitable; however, a correctly designed, set-up and operated system will ensure that any pollutant emissions are minimised.

Carbon dioxide (CO_2), one of the principal combustion products, has been identified as a major contributor to the ‘greenhouse effect’ theory and climate change. CO_2 emissions can be minimised by ensuring optimum ***combustion efficiency.*** Carbon monoxide (***CO***) is also identified as a contributor to the greenhouse effect, and, in addition, is toxic to humans and represents a serious safety hazard. Again, optimum combustion efficiency will minimise, or eliminate, CO emissions.

Combustion of sulphur-containing fuels e.g. coal or fuel oils can result in emissions of oxides of sulphur, collectively known as ***SO_x***[4]. SO_x has been identified as a cause of ‘acid rain’. Production of SO_x can be avoided by use of low-sulphur fuels such as natural gas, LPG or lighter fuel oils. If this is not possible, then flue gases need to be treated to remove SO_x and convert it to inert substances.

Emissions of oxides of nitrogen, collectively termed NO_x[5], from combustion processes have been identified as a contributor to the greenhouse effect and a cause of acid rain. They have also been linked to the recent decline in urban air quality with its resultant health implications. Further information on the mechanisms of NO_x formation and methods of control is presented in Appendix 4.

Since emissions from the combustion of fossil fuels are of major concern, legislation has been introduced in the UK in the form of the 1990 Environmental Protection Act (EPA 90). The legislation is enforced by either Local Authorities or the Environment Agency, depending on the nature of the process and the pollution potential. The Guidance Notes listed in Section 8.5.2 should be consulted for full details on emission limits. A summary is presented in Appendix 5.

The pollution potential of the various commonly used industrial fuels is summarised in Table 3.

Table 3 Pollution potential of common industrial fuels

Fuel	**Particulates**	**SO_x**	**NO_x**
Natural gas			✓
LPG			✓
Light fuel oil		✓	✓
Heavy fuel oil	✓	✓	✓
Coal	✓	✓	✓

4 SO_x includes sulphur dioxide (SO_2) and sulphur trioxide (SO_3).
5 NO_x includes nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O).

6. BURNER CHOICE - FITTING THE TECHNOLOGY TO THE APPLICATION

6.1 Burner Outputs

Commercially-available burners come in a wide range of sizes and outputs. Some burners have a range of heat outputs which can be stepped, e.g. low-fire and high-fire or low/medium/high-fire, or fully modulating across the firing range. The subject of burner control is covered more fully in Section 7. The ratio of the maximum firing rate of a burner to its minimum firing rate is called the ***turndown ratio*** and is an important feature in burner selection. If a wide range of heat inputs to a furnace is required, then a burner system with a good turndown ratio is essential.

6.2 Burner Types

Burners can be broadly classified by their fuel type: gas-fired or oil-fired. Within each classification there are several sub-classifications based on the method of mixing employed, and, in the case of oil burners, the method of atomisation.

Burners can operate with either cold or preheated combustion air. Air preheating greatly improves combustion efficiency, and is the basis of modern burner designs incorporating ***waste heat recovery*** features. If air preheat is to be used, burners capable of dealing with high-temperature combustion air must be used.

The following decision tree (see Fig 8) presents an overview of the burner types currently available. The main categories are broken down further in subsequent overview diagrams (see Figs 9, 12 and 17), followed by detailed information on individual burner technologies.

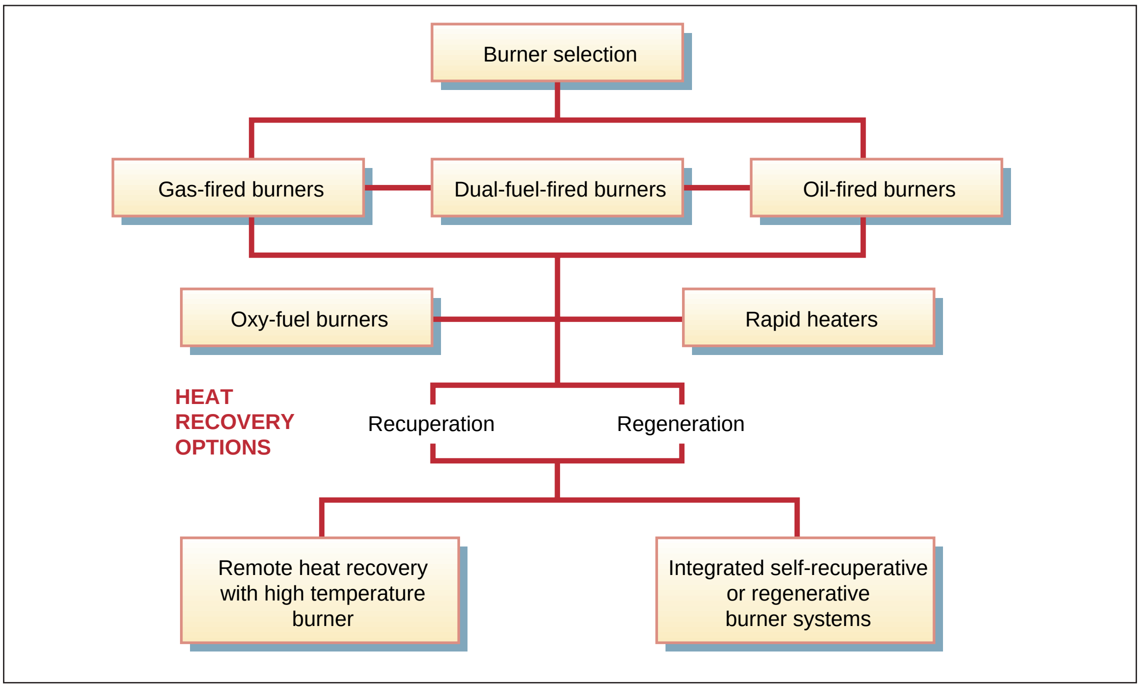


Fig 8 Burner overview

6.2.1 *Gas-fired Burners*

Based on the method of mixing used, gas burners are sub-classified into three main groups:

- premix;
- ***nozzle mix***;
- delayed mix (a variation of nozzle mix).

Fig 9 gives an overview of the broad range of gas-fired burners available, and each type is described in more detail in the following pages.

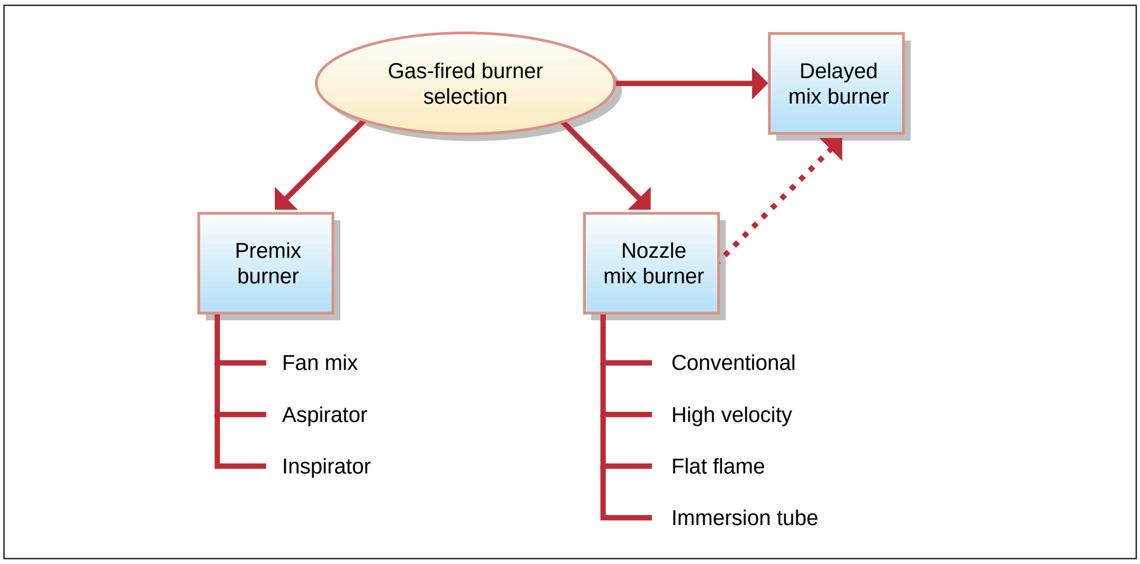


Fig 9 Overview of gas-fired burners

Premix Gas Burners

Premix gas burners combine the air and gas within the burner body and tend not to be operated with excess air. Because of the presence of near ***stoichiometric*** mixtures of fuel and air within the burner body, there is a danger of explosion as a result of ***flashback.*** Most premix gas burners have a mouth composed of a cylindrical or cone-shaped tunnel in a refractory block. This acts as a mini combustion chamber where the mixture can ignite and burn without interference from furnace gases that might snuff it out. The refractory acts as a flame stabiliser and becomes hot, warming the incoming mixture to its ***ignition point.***

There are three types of premix gas burners: fan mixers, aspirators, inspirators. Fan mixers feed regulated quantities of gas and air to a fan or blower which ejects the mixture into the furnace. This type is rarely used as it is most prone to flashback. Aspirators are more widely used. Air is piped from a blower into the aspirator body, which contains a ***venturi.*** The reduction in pressure created by the venturi draws gas into the air stream through an opening in the throat of the venturi (see Fig 10). The gas and air then mix as they leave the venturi. The gas:air ratio is maintained across the entire turndown range of the burner's output.

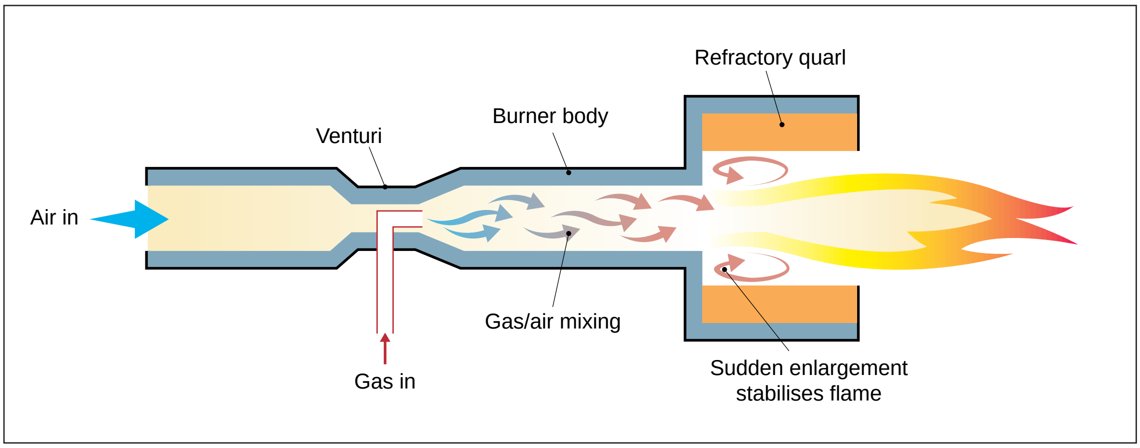


Fig 10 Premix gas burner, aspirator principle

Inspirators operate on similar principles, but it is the gas which creates the suction to draw in the air. A high-pressure jet of gas is blown through a small nozzle called a spud, which is situated in the throat of a venturi. The suction created by the gas draws in air at atmospheric pressure from the opening around the spud. The gas and air then mix as they pass down through the diffuser section of the mixer.

Nozzle Mix Gas Burners

Nozzle mix burners combine separate streams of gas and air at the mouth of the burner, and can utilise large amounts of excess air. The flame from a nozzle mix burner is typically long and slender. Nearly all nozzle mix burners incorporate some kind of tube or refractory tile that, in combination with the burner nozzle, acts as a flame stabiliser. Tubes may be made of stainless steel, heat-resistant alloys, or silicon carbide (for high-temperature applications). The advantage of the tube design is ease of installation, particularly in modern, lightweight, ceramic-fibre-insulated furnaces. Silicon carbide tubes are lightweight and have excellent resistance to thermal shock, thus offering a better service life than conventional refractory tiles (see Fig 11).

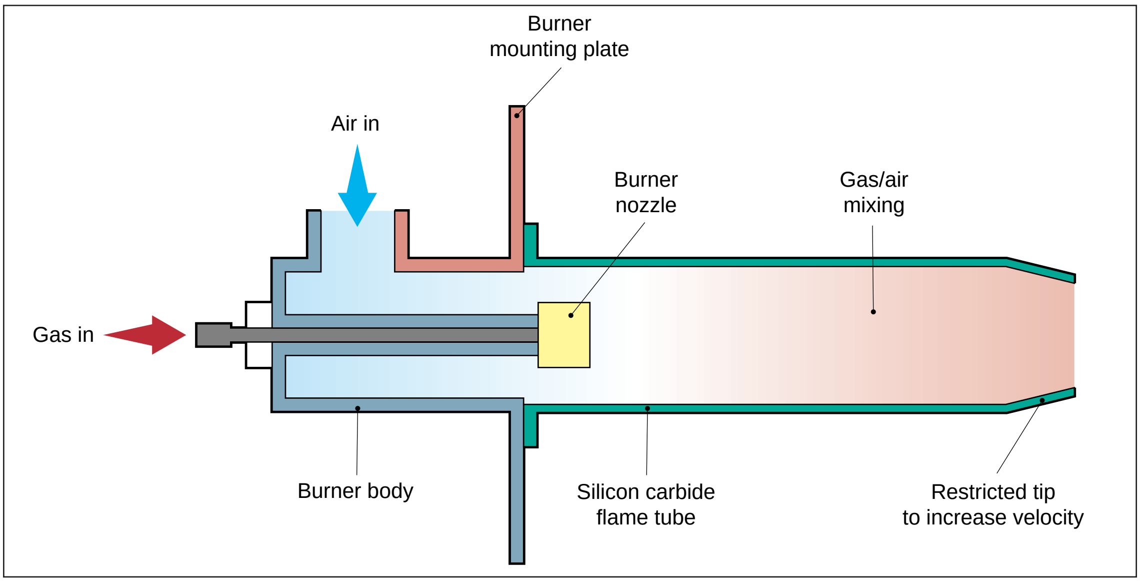


Fig 11 Nozzle mix burner with silicon carbide tube

There are a number of variations on the nozzle mix gas burner:

- *Flat-flame burners* - The tile is flared to project the flame sideways instead of forwards, causing the flame to scrub the refractory walls. The result is that the walls heat up and radiate back in towards the furnace load. The outcome is very uniform heating, which allows the load to pass close to the burner without flame impingement.

- *High-velocity burners* - Where furnaces are required to heat large, densely packed loads, the combustion products may not have enough ***drive*** to reach the cold centre of the load. In these cases, a ***high-velocity burner*** may be used to penetrate deep into the furnace with a high rate of convective heat transfer. The tube or refractory tile of this type of burner is restricted, causing the combustion products to move at a high velocity on leaving the burner mouth.

- *Immersion tube burners* - This variation uses a sealed tube in place of the refractory tile. An immersion tube burner is used in ***controlled atmosphere*** furnaces or to heat tanks of liquid where the flame cannot be allowed to come into contact with the load. The burner is designed to throw the combustion products against the tube walls for maximum heat transfer to the load.

Delayed Mix Gas Burners

This type of burner is similar in concept to the nozzle mix burner, but is designed to mix the fuel gas and combustion air as slowly as possible. The gas and air are introduced into the furnace in adjacent, slow-moving streams, with very little stirring. Mixing and burning occur only where the streams collide. Heat from this combustion radiates into the unburnt fuel, cracking the hydrocarbon molecules into carbon and hydrogen. Carbon particles incandesce until they eventually meet some air and burn. The resulting flame is long, slender and highly luminous. This is ideal for distributing heat evenly throughout a large furnace, using only a small number of burners.

6.2.2 *Oil-fired Burners*

Generally, oil burners are similar to nozzle mix gas burners, but must perform the additional function of ***atomising*** the oil before it can be burnt. Oil burners differ only in the method of oil atomisation employed, which in turn influences the resulting ***flame shape*** and combustion efficiency. As fuel oils are available in a number of grades or 'weights' of varying viscosity, the correct choice of atomisation method is important. The three methods of atomisation commonly used are:

- pressure jet;
- rotating cup;
- twin-fluid (blast atomisation).

Fig 12 presents an overview of the range of oil-fired burners available.

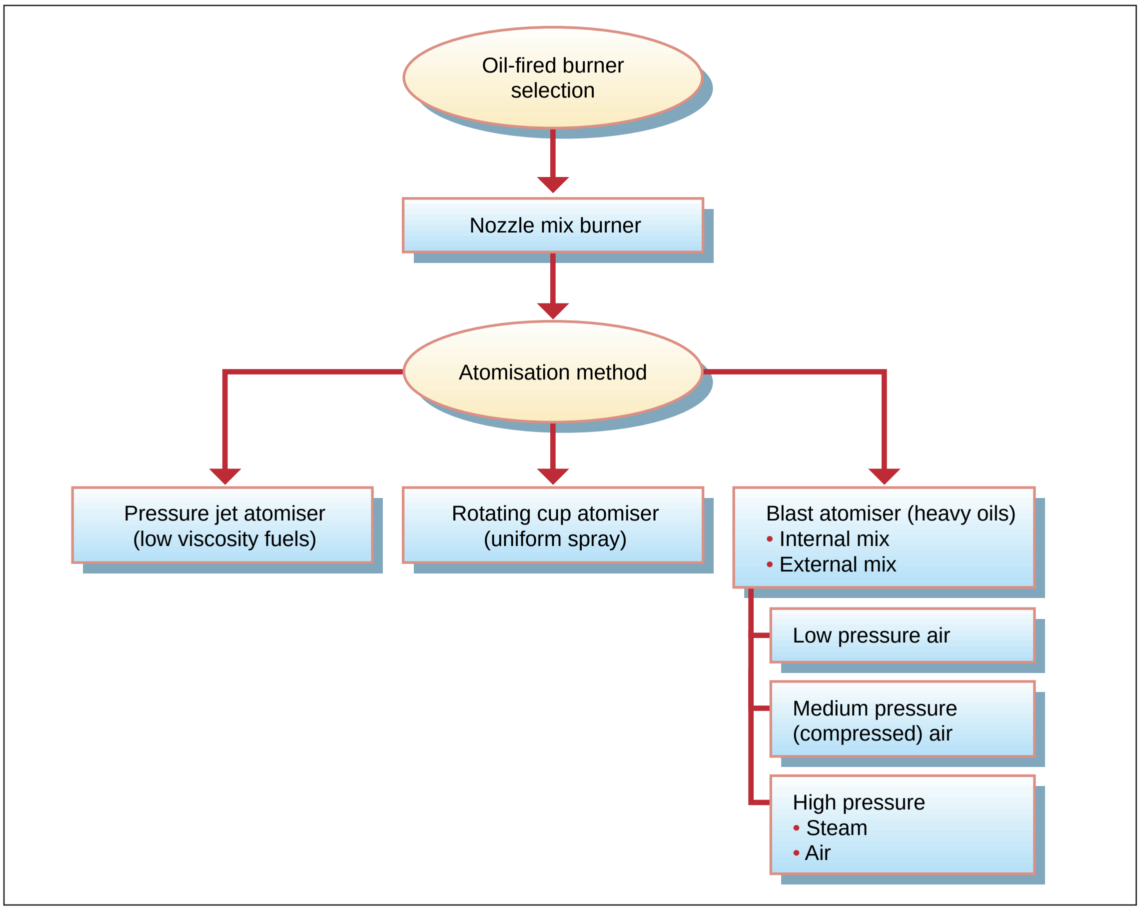


Fig 12 Overview of oil-fired burners

Pressure Jet Atomiser

Oil is pumped at high pressure (7 to 35 bar) through a fine nozzle to produce an expanding conical film that eventually disintegrates into a spray of droplets. A range of fuel oils may be

atomised in this way, but the heavier oils must be preheated to reduce their viscosity to between 70 and 100 ***Redwood seconds.*** Combustion air is introduced around the spray and aids the atomisation process. Because of the dynamics involved, this type of burner has a poor turndown ratio, and it may be necessary to use a number of small, individual burners to achieve the desired flexibility (see Fig 13).

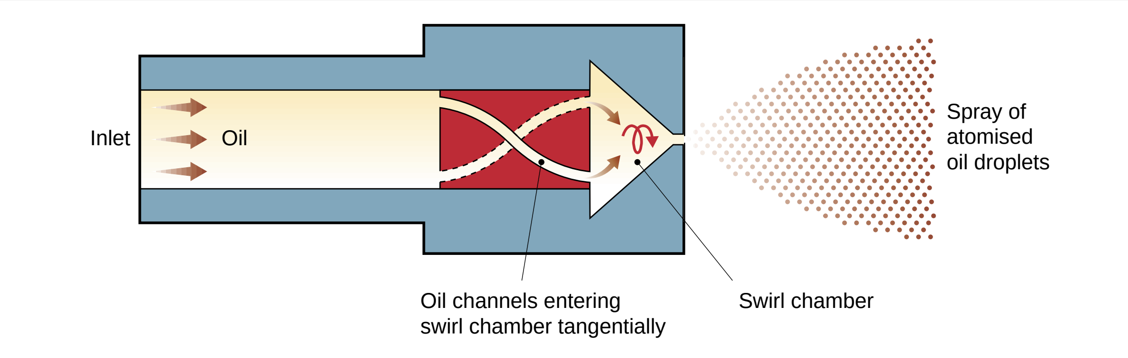


Fig 13 Pressure jet atomiser

Rotating Cup Atomiser

In this type of burner, atomisation is achieved by centrifugal force. The oil is fed by a pipe to the inner surface of a hollow, tapered cup. The cup revolves at high speed, driven by either an electric motor or a turbine driven by a portion of the incoming combustion air (see Fig 14). Centrifugal force causes the oil to spread over the surface and be thrown off the lip. The combustion air passes around the outside of the cup, thereby helping the atomising process and shaping the resulting spray. This type of atomiser achieves a very uniform droplet size over a wide area. Rotating cup atomisers can handle fuels with much higher viscosities (100 to 400 Redwood seconds) than simple ***pressure jet atomisers***, and are less susceptible to blockages caused by grit. In addition, turndown ratios of 5:1 are better than those achievable by pressure jet burners. Rotating cup atomisers can, however, suffer from carbon deposition caused by 'cracking' (sudden chemical decomposition) of oil due to ***radiation*** from the hot surroundings after the burner has shut down.

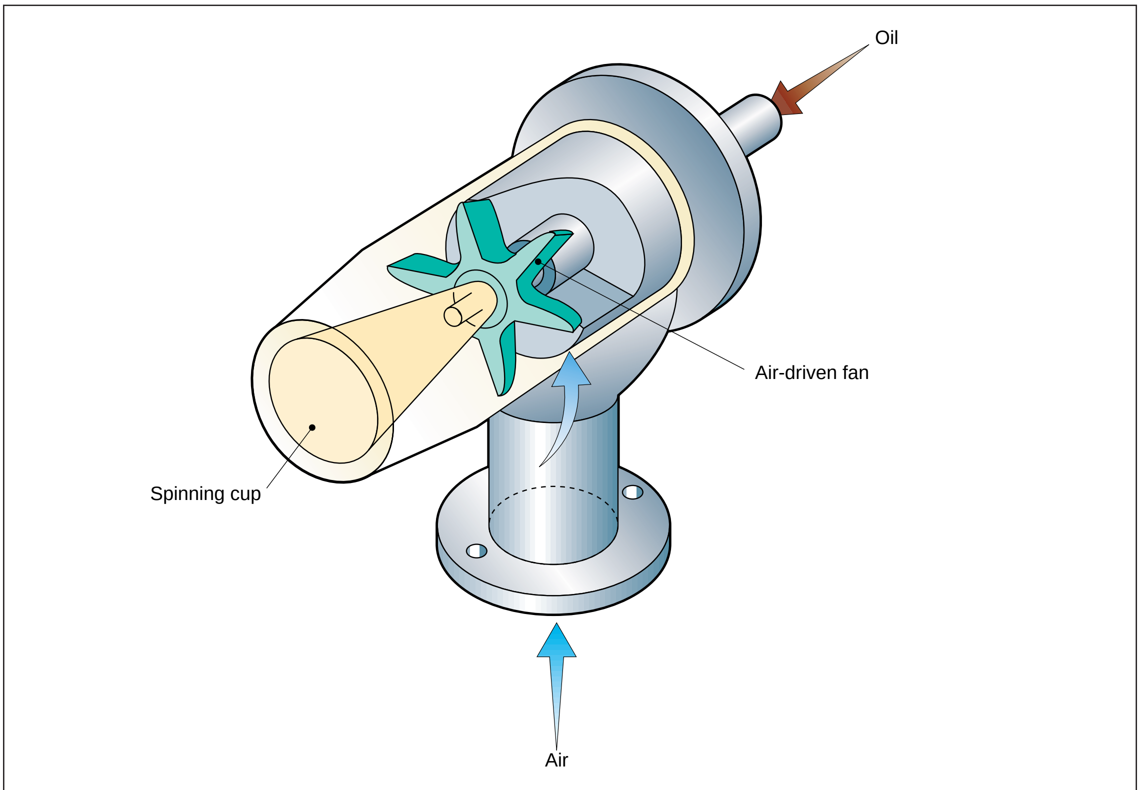


Fig 14 Rotating cup atomiser (air-driven)

Blast Atomiser

Also known as the twin-fluid atomiser, this type of burner uses either steam or compressed air to atomise the oil (see Fig 15). ***Blast atomisers*** can operate at low, medium or high pressure and are further classified as either internal or external mixing, depending on whether the oil and the atomising fluid meet within the body of the burner or at the outlet. All blast atomisers require oil with a viscosity in the range of 70 to 150 Redwood seconds.

- *Low-pressure blast atomisers* use air at 105 to 115 kPa as the atomising medium, usually supplied from a single-stage centrifugal fan. Most, or all, of the combustion air is used as the atomising medium. Mixing of the oil and air is efficient and there is usually little requirement for excess air; however, the turndown ratio is rarely better than 2:1. Higher turndown ratios (up to 5:1) can be achieved by using only a small proportion of the air (20%) as the atomising medium and introducing the remainder through ports around the burner.
- *Medium-pressure blast atomisers* use air at 230 to 300 kPa. Less than 10% of the combustion air is required to atomise the fuel. Usually, this is supplied by means of a rotary compressor. The remaining combustion air is introduced as ***secondary air*** around the burner and can be preheated without danger of cracking the fuel within the burner. This enables higher flame temperatures to be reached. Turndown ratios of 10:1 can be achieved.
- *High-pressure blast atomisers* use steam or air at pressures in excess of 300 kPa. Air atomisers operate on similar principles to medium-pressure blast atomisers. Steam atomisers are used only where large amounts of cheap steam are available (between 0.3 and 0.5 kg of steam are required per kg of oil, thus significantly adding to operating costs).

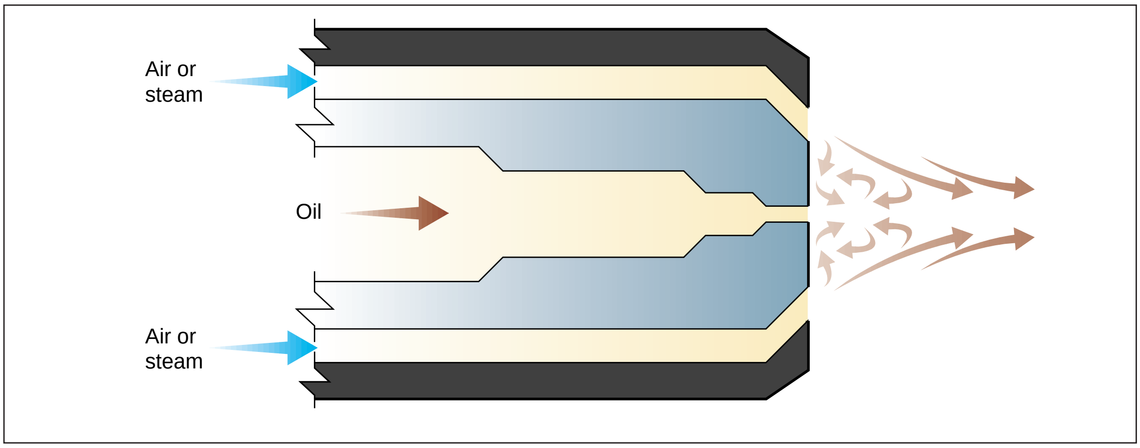


Fig 15 Blast atomiser (internally mixed)

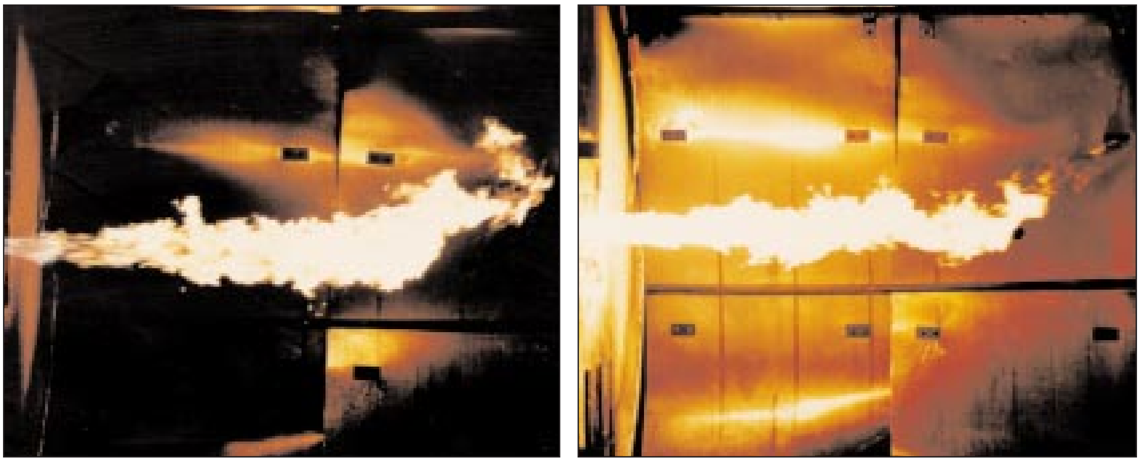
6.2.3 *Dual-fuel-fired Burners*

Dual-fuel firing presents opportunities for firing different fuels as external conditions dictate. Typically, a dual-fuel burner might be designed to burn either natural gas or fuel oil, or a combination of both, and would combine the features of both a nozzle mix gas burner and an oil burner appropriate to the grade of fuel oil to be burned. This type of burner may be used for economic reasons, for instance to take advantage of interruptible gas tariffs or fluctuating fuel prices, or for technical reasons, e.g. increasing the radiative component of the flame by addition of an oil-fired element.

Another reason for dual-fuel firing may be to take advantage of an alternative, low-cost fuel available in varying quantities, e.g. biogas, coke oven gas, or waste oils. Some fuels of particularly low ***calorific value (CV)*** may not be capable of sustaining a flame on their own and may need to be supplemented by the addition of another fuel, e.g. natural gas, with a higher CV. Dual-fuel burners should be designed to cope with the different combustion characteristics of the two fuels, and, therefore, the intended fuels should be clearly stated to the supplier when the burner is selected.

6.2.4 *Oxy-fuel Burners*

Oxy-fuel burners are essentially similar in concept to conventional fuel-air burners, but may have additional design features to cope with the high flame temperatures achieved. Burners may be designed to fire natural gas or fuel oils, or both in dual-fuel designs. As well as the conventional fuels, oxy-fuel burners can burn a range of other fuels. Due to the higher flame temperatures achievable, they have the particular advantage of being able to burn waste gases of low CV. The flame produced from oxy-fuel firing is typically, but not necessarily, long and luminous (see Fig 16), ideal for achieving even heating over large surfaces. Typical applications include glass melting, metal reheating and ladle heating.



Gas burner   Oil burner

Fig 16 Oxy-fuel flame

6.2.5 *Rapid Heaters*

Rapid heating systems are used to raise the temperature of the stock very quickly, when conventional methods might damage the stock if it is left in the furnace for an excessive time period. Rapid heaters tend to use high-velocity burners to create a turbulent atmosphere, thus promoting high rates of convective heat transfer. In some systems, the flame impinges directly on the surface of the stock; in others, the combustion chamber is shaped to encourage the combustion gases to flow at high velocity over the surface of the stock.

6.3 Combustion Air Preheat: the Technology Available

In all high-temperature processes, some loss of heat through waste gases is inevitable. In many cases it is possible to recover some of that heat. A good indicator that there is potential for waste heat recovery is a high flue gas temperature (over 1,100°C) and this is the first thing to check. Other factors to consider are the volumetric gas flow rate and the degree of contamination of the waste gas stream.

One of the most cost-effective uses for the heat is to preheat the combustion air, which increases flame temperatures and boosts the thermal efficiency of combustion. Alternatively, it is possible to use the heat to preheat incoming stock. Such a practice is called load recuperation. As far as burners go, there are two conventionally accepted methods of recovering the heat: recuperation and regeneration. This approach uses a recuperative or ***regenerative burner*** system. There are several types of burner and combustion system in each category and Fig 17 presents an overview of the choice available. For more information on the assessment of the quantity and quality of heat available, and heat recovery techniques in general, see Good Practice Guide 13, *Waste heat recovery from high temperature gas streams.*

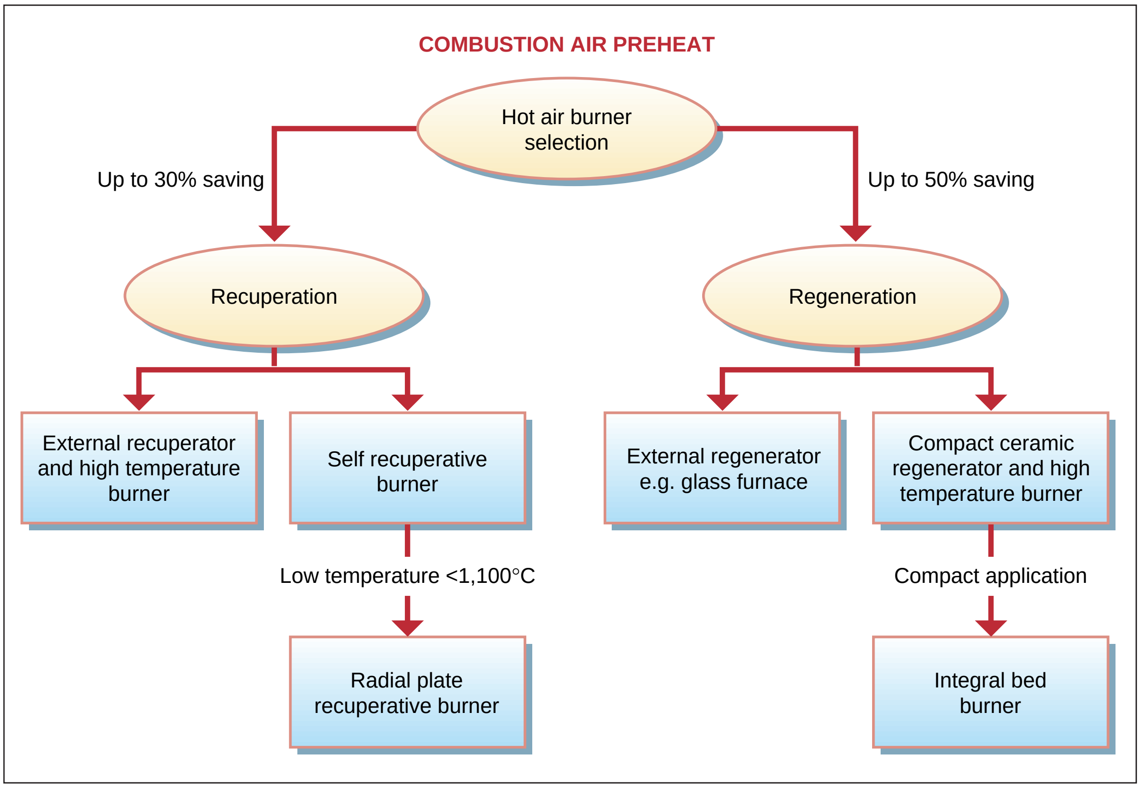


Fig 17 Overview of heat recovery methods

6.3.1 *Recuperation*

At its simplest, a ***recuperator*** consists of an annular tube arrangement in which hot gases are passed through the inner shell and the cold combustion air is preheated by passing through the outer shell (see Fig 18). Heat transfer takes place by radiation. Recuperators may be ***remote***, where the source of hot gases and the cold combustion air are separated by a distance. In this case the recuperator is usually mounted in the furnace flue. The combustion air is ducted through the recuperator and then to the burner, which must be capable of handling high-temperature air. The burner, therefore, is usually constructed from materials capable of withstanding high temperatures. These burners are usually slightly more expensive than conventional cold-air burners. Installation requirements are generally more complex, since extra insulated ductwork is required to carry the preheated air from the flue-mounted recuperator to the burner. Maintenance requirements and costs are also likely to be slightly higher than those for an equivalent cold-air burner system.

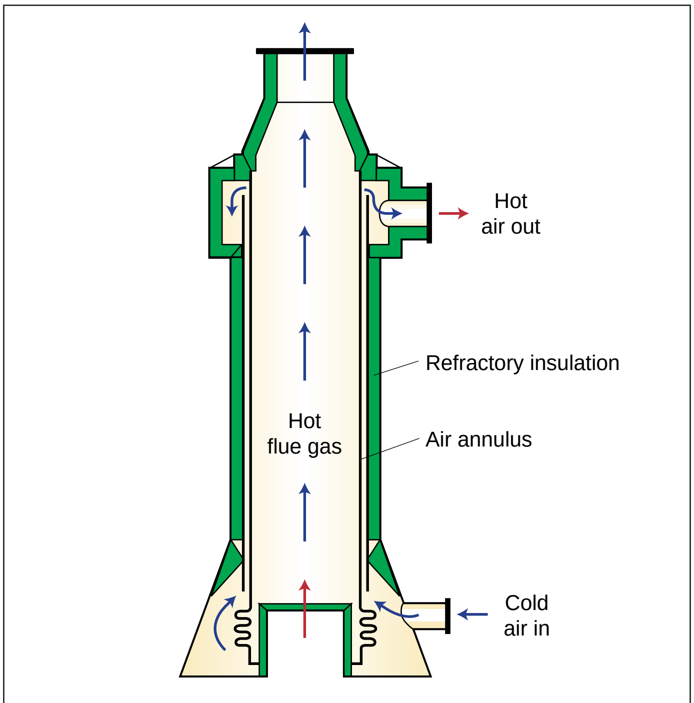


Fig 18 Double shell-type recuperator

Self-recuperative Burners

Burners have been developed which incorporate a recuperator within the body of a high-temperature burner; these are known as ***self-recuperative burners*** (see Fig 19). An ***eductor*** is used to draw hot waste gases through the in-built recuperator, thus preheating the incoming cold combustion air. These burners can be relatively easily retrofitted to existing furnace installations, although some modifications to the waste gas flue arrangements will normally be required. Purchase and maintenance costs are likely to be higher than for a simple cold-air burner. The major advantages are compactness and high thermal efficiency, as neither the heated air nor the waste gases need to be transported long distances, so heat losses are eliminated. Compared to conventional cold-air combustion systems, fuel savings of up to 30% can be achieved. Self-recuperative burners are best suited to applications with high gas temperatures (above 800°C) and low levels of contamination in the flue gases. Special variations are available for lower flue gas temperatures. The main disadvantage with self-recuperative burners is that, because the source of heat and the point of waste gas removal are the same, it can be difficult to achieve a uniform distribution of heat within the furnace. This can cause problems, e.g. in heat treatment applications. A conventional high-temperature burner with a remote recuperator is more suitable in these applications.

Low-NO_x self-recuperative burners are available from a number of manufacturers.

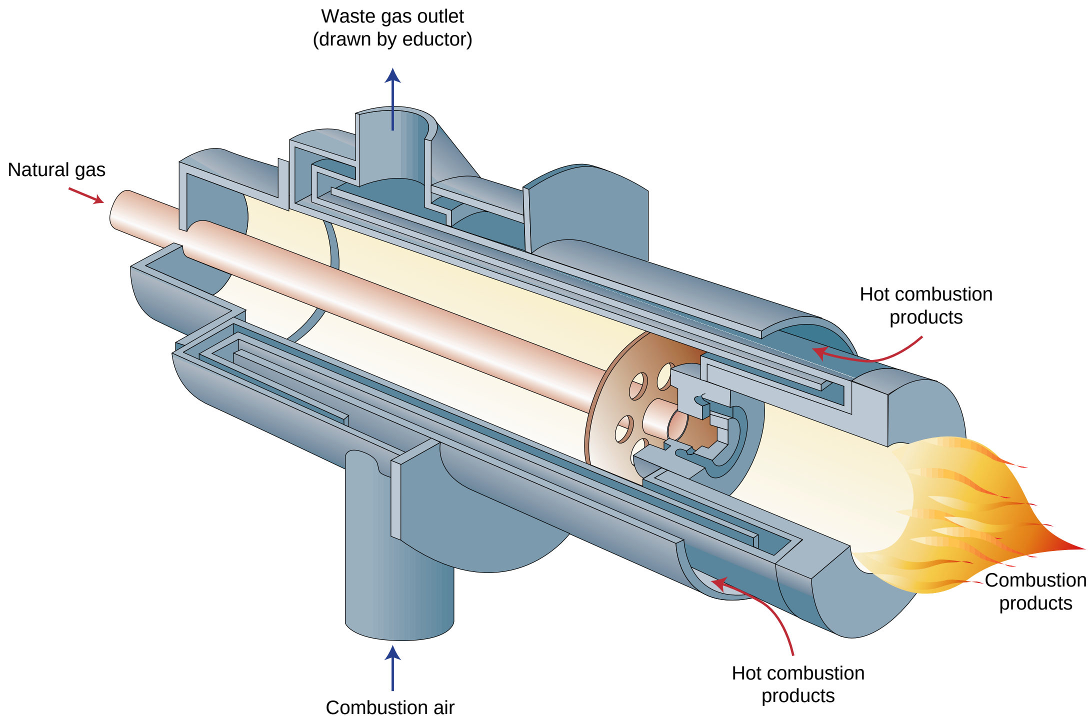


Fig 19 Self-recuperative burner

6.3.2 *Regeneration*

Regeneration, or regenerative firing, is a means of recovering waste heat from exhaust gases by cyclical firing of paired combustion systems. There are a variety of methods used, but all operate on the same principle. As one burner fires, the hot combustion products are exhausted through the second burner, which incorporates some form of heat store and recovers the heat from the exhaust. After a period of time the cycle reverses and the incoming combustion air is heated by passing over the heat store. Such systems have high thermal efficiency and can offer fuel savings of up to 50% compared to conventional cold-air combustion systems. Large-scale static ***regenerators*** are an established technology but are restricted to large furnaces such as those in the glass, iron, and steel industries.

Compact Ceramic Regenerators

Compact ceramic regenerators consist of a pair of regenerators that may be either remote or close-coupled with a pair of high-temperature burners (see Fig 20). The regenerators are about the size of a domestic dustbin and filled with a bed of ceramic spheres. The burners are operated in pairs, with a cycle time of 60 to 120 seconds. The regenerators can be susceptible to fouling, depending on the fuel used and the application, in which case regular cleaning will be necessary. Therefore, the regenerators should be designed to be readily accessible for cleaning purposes.

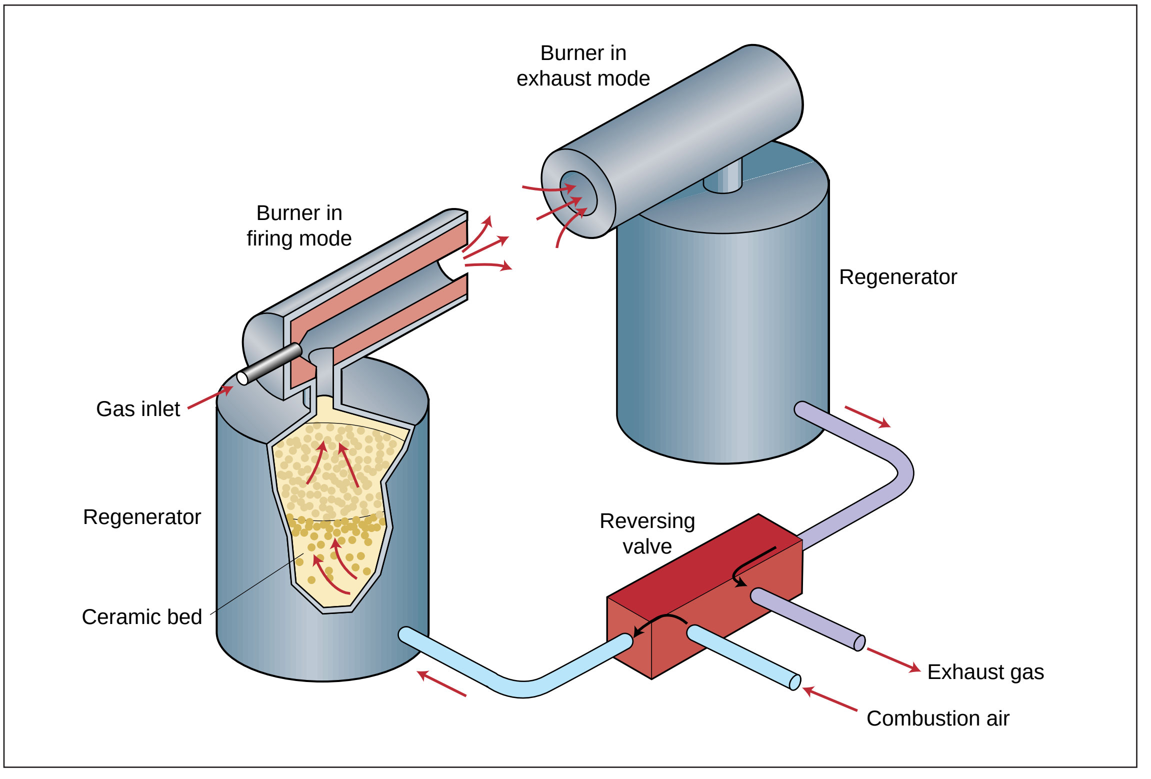


Fig 20 Compact ceramic regenerative burner system

Impulse-fired Regenerative Burners

Impulse-fired regenerative burners are a variation of the regenerative burner system. Each burner fires alternately for approximately 15 seconds, and the burners switch between full fire and zero very rapidly; there is no flow modulation. The efficiency of heat recovery is comparable to conventional regenerative burner systems. However, the fluid flow systems are simpler, so capital costs are lower. The pulse firing creates a turbulent atmosphere within the furnace and is ideally suited to processes requiring a convective heat transfer mechanism.

Integral Bed Regenerative Burners

The integral bed regenerative burner (IBB) incorporates a thermal store, in the form of a bed of ceramic spheres, within its body (see Fig 21). Burners are mounted in pairs and operate alternately, as in conventional regenerative firing systems. The compact nature of the IBB means that it is easy to retrofit and ideally suited to either small or tunnel furnaces where, previously, regenerative firing would not have been possible. IBBs are available in a range of sizes, from 65 kW to over 5 MW. As with compact ceramic regenerators, the regenerator beds may be susceptible to fouling (depending on the application) and will need to be cleaned on a regular basis.

Radiant tube versions are also available, comprising a pair of regenerative burners connected by a sealed ceramic or metal tube, usually in a U-tube arrangement. This development enables regenerative firing technology to be readily applied in controlled atmosphere furnaces and other indirectly fired processes.

Low-NO_x regenerative burners are available from several burner manufacturers.

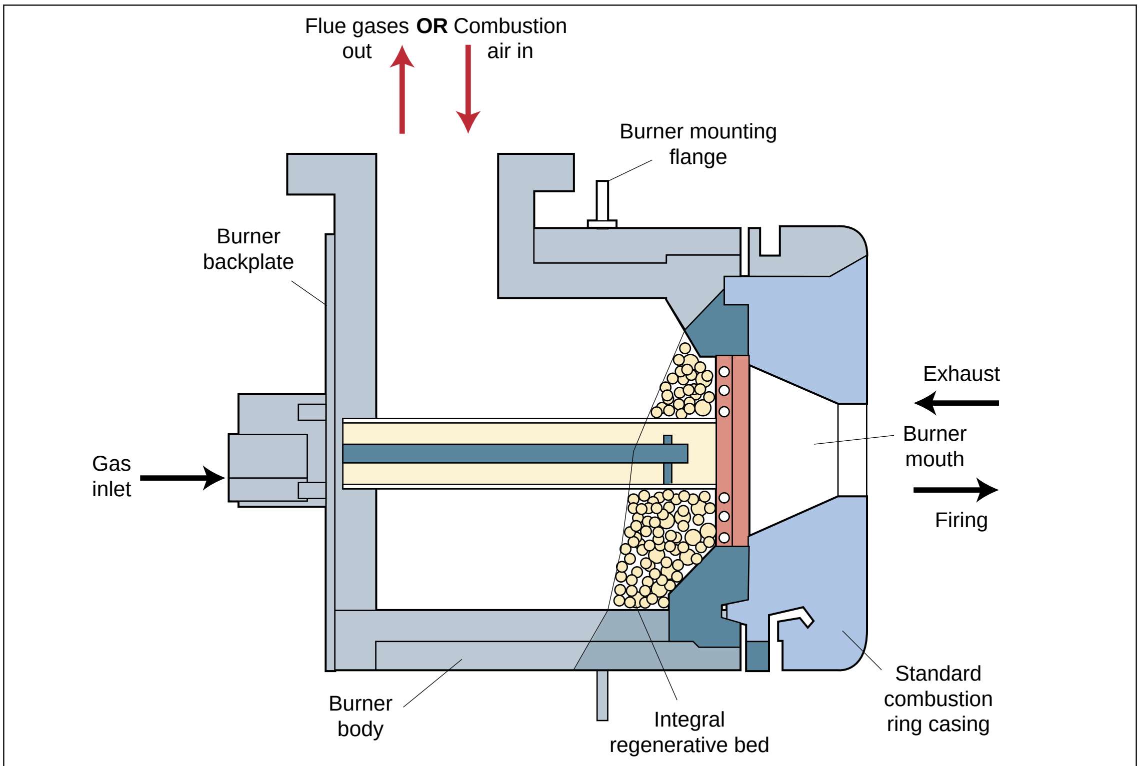


Fig 21 Integral bed regenerative burner

6.4 Relative Costs

There are many advantages in terms of improved fuel efficiency, and hence lower running costs, from selecting high-efficiency burners that utilise waste heat recovery methods, rather than standard cold-air burners. Any such decisions would normally be accompanied by a detailed financial analysis. The following example illustrates a typical evaluation process.

The example is based on the heating of steel billets to 1,250°C in a continuous furnace over an eight-hour period. The furnace is assumed to operate for 15 hours per day and 45 weeks of the year. The example in Table 4 compares the relative costs of three types of burners firing two different fuel types. Fuel costs are assumed to be £3.18/GJ for gas oil and £2.55/GJ for natural gas. It has been assumed that the life of each burner is ten years.

Three financial analysis methods have been applied: net present value (NPV), internal rate of return (IRR), simple payback. Both in terms of simple payback and IRR, the gas-fired self-recuperative burner is the best option. However, if the savings are discounted at 10% per annum over the life of the burner, the gas-fired regenerative burner offers the best return and would make the greatest contribution to cash flow (but requires a greater initial outlay).

Table 4 Financial analysis of energy efficient burner installation

		Burner type					
Fuel		**Gas-oil-fired**			**Natural-gas-fired**		
Burner type		**Cold-air**	**Self-recuperative**	**Regenerative**	**Cold-air**	**Self-recuperative**	**Regenerative**
Costs							
Ancillaries (storage/piping)	(£)	2,500	2,500	2,500			
Burner capital cost	(£)	14,000	22,000	36,000	12,000	20,000	34,000
Annual maintenance cost	(£)	600	1,500	2,700	400	1,000	1,800
Annual fuel cost	(£)	74,823	52,376	37,411	60,000	42,000	30,000
Lifetime years	(Yrs)	10	10	10	10	10	10
Annual fuel and maintenance cost	(£)	75,423	53,876	40,111	60,400	43,000	31,800
Capital	**(£)**	**16,500**	**24,500**	**38,500**	**12,000**	**20,000**	**34,000**
Saving	**(£)**		**21,547**	**35,312**	**15,023**	**32,423**	**43,623**
Present value saving							
Year	Discount factor						
Year 0	1.0000	-16,500	-24,500	-38,500	-12,000	-20,000	-34,000
Year 1	0.9091		19,588	32,102	13,657	29,476	39,658
Year 2	0.8264		17,806	29,182	12,415	26,794	36,050
Year 3	0.7513		16,188	26,529	11,286	24,359	32,773
Year 4	0.6830		14,716	24,117	10,260	22,144	29,793
Year 5	0.6209		13,378	21,925	9,328	20,131	27,085
Year 6	0.5644		12,162	19,932	8,480	18,301	24,623
Year 7	0.5131		11,056	18,120	7,709	16,637	22,384
Year 8	0.4665		10,051	16,472	7,008	15,125	20,349
Year 9	0.4241		9,138	14,975	6,371	13,750	18,499
Year 10	0.3855		8,307	13,614	5,792	12,500	16,818
Net present value	**(£)**		**107,890**	**178,468**	**80,306**	**179,217**	**234,032**
Simple payback	**(Yrs)**		**1.14**	**1.09**	**0.80**	**0.62**	**0.78**
Internal rate of return	**(%)**		**88%**	**92%**	**125%**	**162%**	**128%**

For further information on financial analysis, see Good Practice Guide 69, *Investment appraisal for industrial energy efficiency.*

Fig 22 shows the energy flow, in the form of Sankey diagrams, for the three burner types: cold-air, self-recuperative and regenerative.

Specific energy consumptions for the three burners are:

Cold-air burners	3.26 GJ/t
Recuperative burners	2.28 GJ/t
Regenerative burners	1.62 GJ/t

With minor changes in terms of heat transferred to the stock and quantity of waste heat produced, the Sankey diagrams are the same for gas and gas oil.

The regenerative and recuperative systems offer a fuel saving over the cold-air system of 50% and 30% respectively. The base case for comparisons is the oil-fired cold-air burner.

Fuel costs

Gas oil	£3.18/GJ
Natural gas	£2.55/GJ

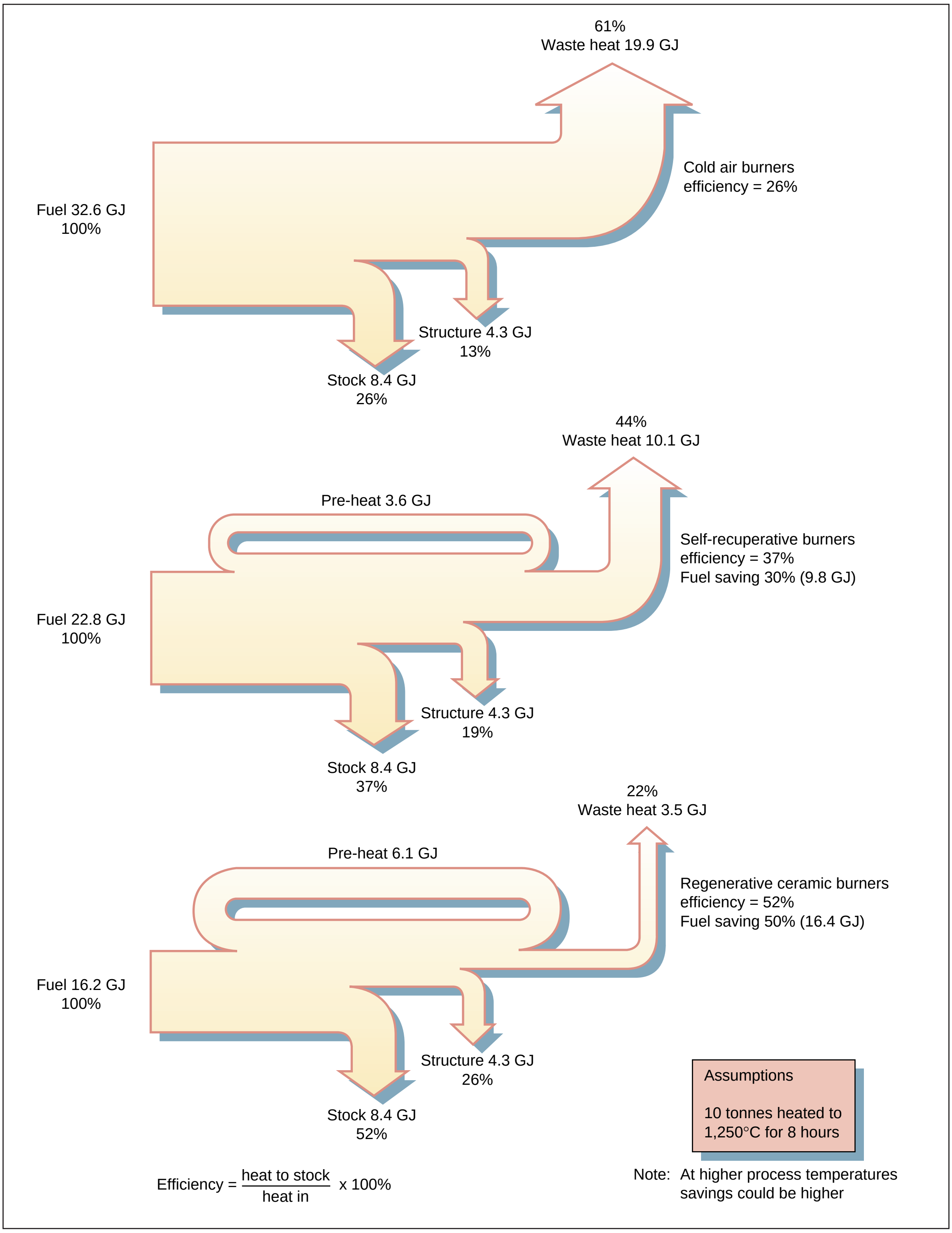


Fig 22 Sankey diagrams comparing energy flow of three burners

6.5 Burner Maintenance and Safety

Regular burner maintenance is an essential requirement for safe, reliable, efficient and clean combustion. Most burner manufacturers and furnace installers will offer a biannual or annual service contract, or training on their equipment for in-house maintenance personnel; this is strongly recommended.

When selecting or specifying a burner, it is important to choose a model that has been designed with ease of maintenance in mind. ‘Back-end extraction’ is a useful feature, meaning that components likely to require replacement on a regular basis, e.g. flame ionisation detectors, can be withdrawn and refitted without removing the entire burner assembly from the furnace. The

cost of consumable items, e.g. refractory tiles or tubes, flame ionisation detectors, and spark ignitors, should be checked as these can add significantly to the running cost of an installation.

In all cases, energy monitoring is an essential aid to early identification of maintenance problems, and is therefore strongly recommended. This can take a variety of forms: from a simple daily, weekly or monthly record of fuel consumption and comparison with stock throughput, to a fully computerised furnace management system.

Safety controls, e.g. flame failure detection and shut-down systems, are an essential element of all combustion systems. These controls are discussed in more depth in Section 7.

The installation of some burners may be required in hazardous areas, e.g. in petrochemical plant installations where flammable gases may be present. Burner manufacturers may offer intrinsically safe versions of their burner and control systems. These should be clearly specified when required.

The subject of plant maintenance is covered in more detail in Good Practice Guide 217, *Cutting energy losses through effective maintenance (Totally Productive Operations)*.

7. BURNER CONTROLS

7.1 Introduction to Burner Controls

The installation of appropriate controls is paramount in ensuring the safety and efficiency of the burner and the furnace system as a whole. Burner controls range in complexity from simple on/off devices to computer-controlled multi-burner optimising systems. Selection of the most appropriate control technology is as important as selection of the burner itself. Manufacturers may supply their burners as 'packaged' units with all necessary controls ready-fitted. All that is required before operation is mounting on the furnace, connection of fuel and power supplies, and commissioning.

7.2 Overview of Burner Controls

The main elements to be considered in burner control are shown in Fig 23.

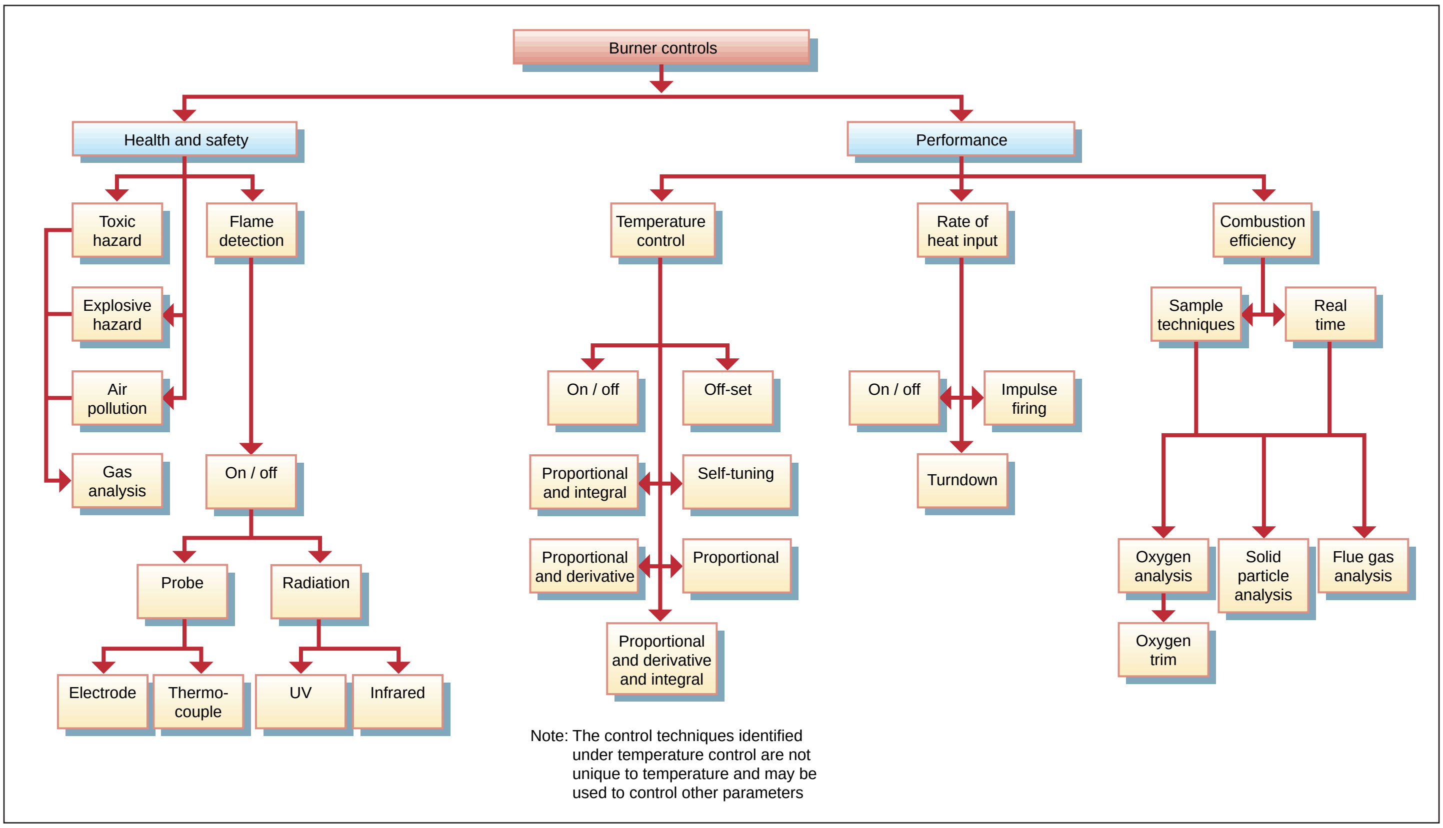


Fig 23 Overview of burner control parameters

7.3 What is Control?

Control can be defined as the attainment of a required set condition, followed by the monitoring ***(measurement)*** and adjusting (as necessary) of the parameters that influence the realisation of that condition.

Fig 24 overleaf illustrates the basic principles of a control system, using ***temperature control*** as an example.

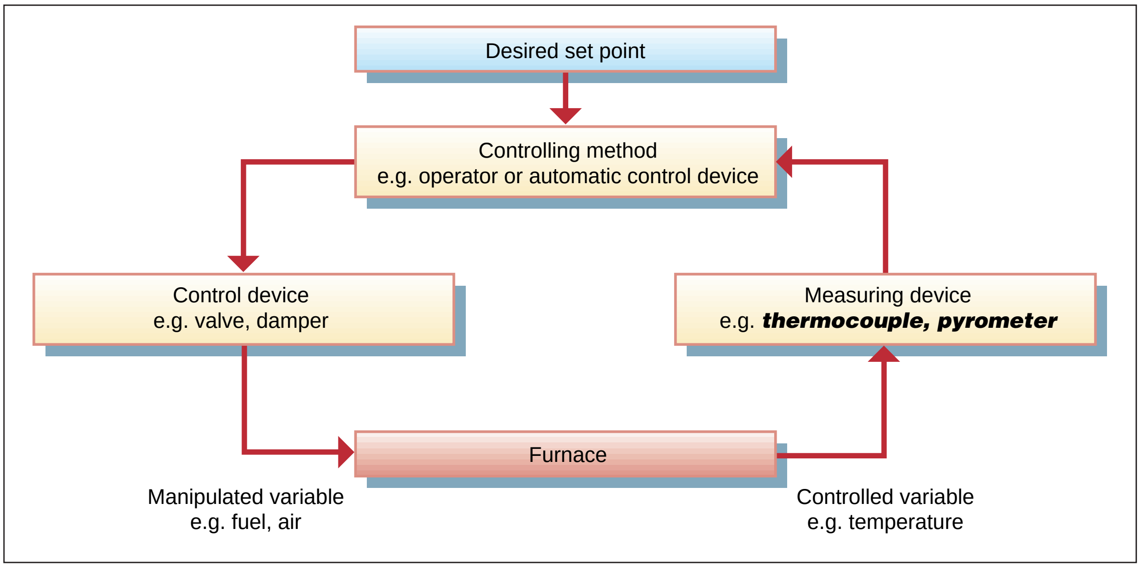


Fig 24 Temperature control example

7.4 Health and Safety Controls

Maintenance of adequate safety and avoidance of environmental hazards are prerequisites in burner control. Areas that must be considered include: light-up sequence; flame failure; potential explosive and toxic hazards; air pollution. British Standard BS EN 746-2: 1997 must be consulted for full details on the safety requirements for combustion and fuel handling systems (see Section 8.5).

7.4.1 *Ignition and Flame Failure Controls*

Most burners should be fitted with automatic systems that control start-up and operation. Larger furnaces, e.g. glass furnaces or steel reheating furnaces, are usually started up under manual supervision, so such controls are not necessary. Start-up sequences require a pre-purge to rid the burner and combustion chamber of any combustible gases. Most modern gas burners of less than 1 MW are fitted with simple spark ignitors, although gas-fired pilot lights are usually available as an option. Spark ignition and pilot flames are not practical for most oil-fired combustion systems, in which case an LPG-fired (or natural-gas-fired if available) pilot flame is usually employed.

It is essential to know the following: that the burner has fired during the ignition sequence; if the flame fails during operation. In either event, without a suitable flame failure device there could be an accumulation of fuel in the furnace chamber with a major risk of fire or explosion.

Flame failure devices consist of two essential components:

- a sensor to detect the presence of the flame;
- a control circuit to turn off the fuel supply if no flame is detected.

The control circuit is normally a fail-safe device incorporating an electronic circuit. While the flame exists, the sensor allows current to flow through the circuit, keeping the fuel valve open and allowing fuel to flow to the burner. If the flame fails, the current ceases to flow and the valve closes to shut off the fuel supply. An example of a flame failure control device is shown in Fig 25.

It is normal for each burner to be fitted with its own flame failure detection device; on multiple burner installations each burner would be automatically shut down in the event of flame failure.

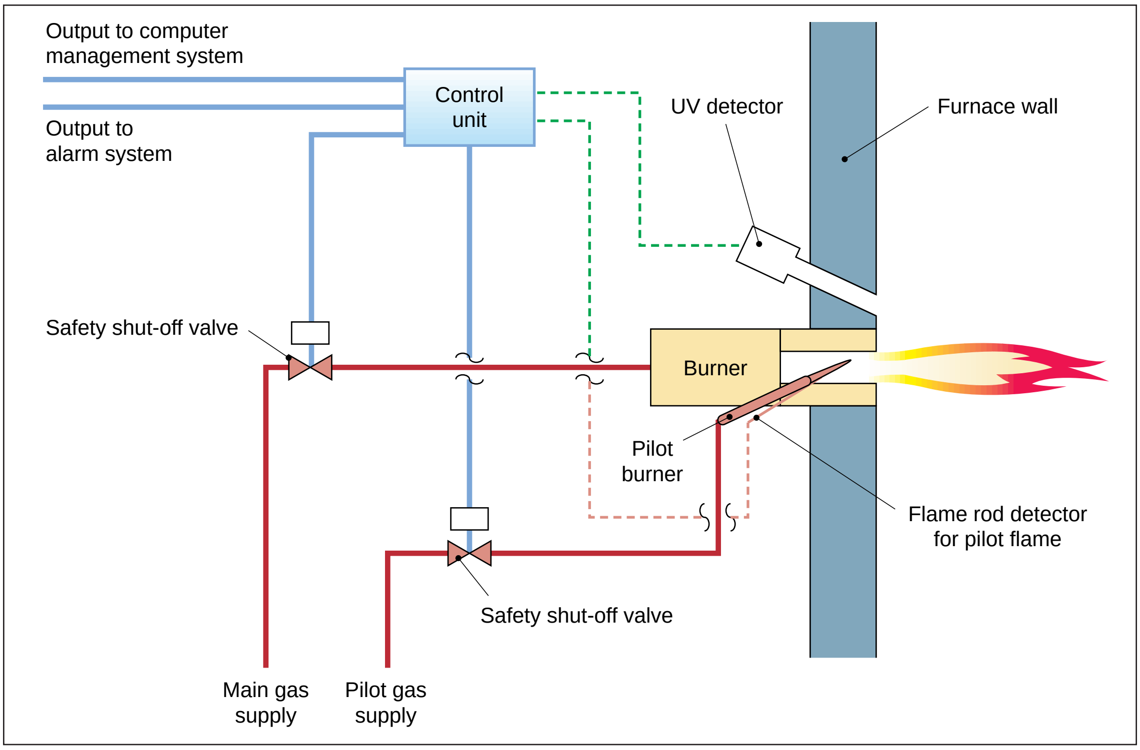


Fig 25 Flame failure control device for pilot-operated gas-fired burner

7.4.2 *Flame Detection Systems*

There are two basic types: either a probe inserted into the flame or a remote radiation detector.

Probe Detector

Any property of the flame may be used to provide the detector signal. A thermocouple in the flame uses the high temperature of the flame to generate a voltage signal that changes when the flame fails due to the drop in temperature. A cheaper alternative is the use of an electrode immersed in the flame. This detects the slight flow of current through the ionised gases present in the flame and is known as a Flame Ionisation Detector (FID), or flame rod. It is commonly used in modern gas-fired burner systems.

Radiation Detector

These detectors make use of either the infrared or ultraviolet (UV) radiation emitted by flames. Photocells tuned to the specified wavelengths are focused onto the burner mouth to monitor the presence of the requisite wavelengths. The photocell gives a high output when the flame is present and a low output if the flame fails. As furnace walls can emit infrared after the burner has been shut off, care must be taken in siting an infrared detector. UV detectors do not suffer from this problem since there is no emission of UV from the furnace walls. Radiation detectors are non-contact and less likely to be damaged or fouled compared to probe detectors. Radiation detectors are normally used on larger burner installations and on oil-fired burners.

CAUTION!

Some types of flame detector may fail in an unsafe condition. Normal start-up procedures include a self-check of the flame failure device, ensuring that any fault is detected before the burner fires. However, problems may arise when a furnace is operated continuously. For this reason it is recommended that burners used in continuous applications either are fitted with automatic, self-checking flame failure controls or have a regular (every 24 hours) shut-down and re-start in order to verify the integrity of the flame detection system.

7.5 Process Control Theory

Process control is a complex subject and is outside the scope of this Guide. There are several textbooks available that provide details on the theory behind process control. Most modern process control applications use a form of multi-function controller that combines ***proportional, integral*** and ***derivative*** control actions in one unit. This is called a **PID,** or three-term, controller.

The aim of ***PID control*** is to ensure that the process approaches the desired ***set point*** condition quickly and smoothly, with minimum overshoot. The three modes must be tuned so that the process gives satisfactory performance for all foreseen operating conditions. This can be very difficult and time consuming, and would normally be carried out by the commissioning engineer. Recently, auto-tuned PID controllers that can simplify and speed up the process have been introduced.

7.5.1 *Self-tuning Control*

Auto-tuned PID controllers can minimise the time required to tune conventional PID controllers. They do, however, have some of the drawbacks of manually-tuned controllers. Once tuned, the controller bands are fixed and unable to adapt to variations in plant behaviour, e.g. changes in plant loading or variations in heat transfer characteristics. This can lead to a poor overall performance of the PID controller. The use of bi-linear self-tuning controllers (STCs) can overcome the problem (further details can be found in Future Practice Report 83).

A bi-linear STC uses two computational models, one for parameter estimation and the other for control law implementation. The controller operates by minimising the uncertainty of a parameter that characterises the plant. The estimated parameters are used to continually update the controller and to operate a closed loop in conjunction with some predefined control objective (see Fig 26).

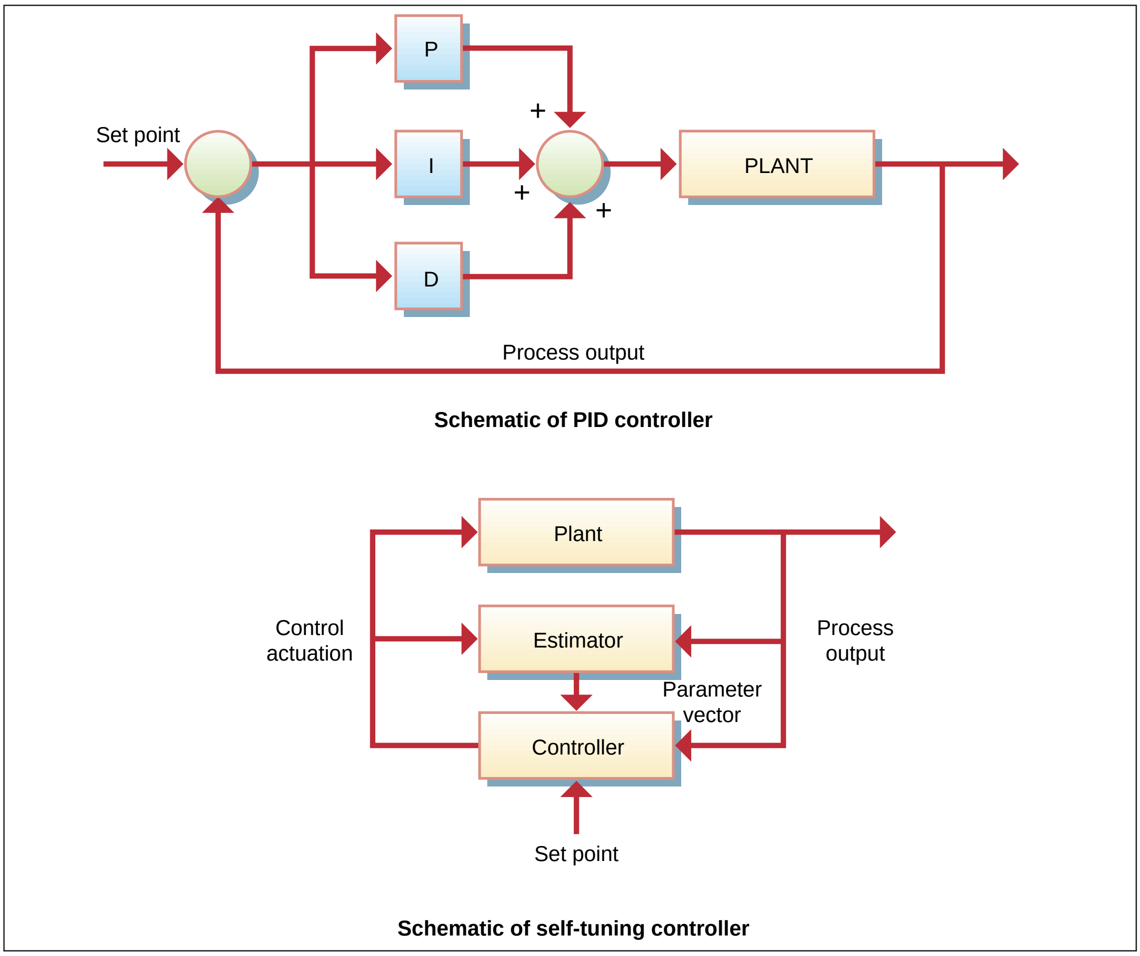


Fig 26 PID and self-tuning control

7.6 Programmable Logic Controllers

Control of burners and furnaces, and other industrial processes, has traditionally been achieved by use of electromechanical temperature/process controllers acting on relays to sequence valve operations, motor drives and other mechanical aspects of plant operation. The advent of the microprocessor has resulted in the development of programmable logic controllers (PLCs). These have replaced hardwired relay logic schemes with software-made connections between inputs and outputs. Thus, any changes required in plant sequences or set points may be achieved by reprogramming of the PLC rather than rewiring of the relay logic.

The major advantages of PLCs are low cost and increased flexibility; their modular design allows control schemes to be expanded to encompass as many aspects of plant operation as required. Most modern PLCs incorporate three-term control (PID) routines as standard and are thus capable of controlling all aspects of temperature, pressure, and flow control required in burner and furnace operations. PLCs may be linked to mimic systems, as mimic panels, or displayed on VDU screens, allowing easier control by supervisors and operators. They are also readily interfaced with personal computers, thus providing accessible real-time monitoring and control of furnaces and other plant, together with data logging facilities for analysis and reporting of batch and shift operations.

CAUTION!

PLCs are ideal for process monitoring and control, but, like all electronic devices, can suffer from reliability problems. For this reason, essential safety functions such as flame detection and automatic shut-down controls must be divorced from PLC control by means of independent, hardwired safety circuits. Refer to HSE Guidelines, *Programmable Electronic Systems in Safety-Related Applications* (see Section 8.5).

7.7 Choice of Control Method

The major considerations in selection of the most appropriate control technique are: how precise the control must be; how difficult the process is to control, e.g. in many applications a wide temperature range may be acceptable. The simplest controller is often selected for ease of operation and the lowest initial cost. However, the simplest controller may not be the most cost-effective option, particularly in terms of fuel efficiency and overall running costs.

Selection of the most appropriate controller type may be approached in several ways:

- process reaction curve;
- physical thermal system analysis;
- previous experience;
- experimental testing.

Examples of process reaction curves are shown in Fig 27 overleaf. These indicate how the temperature of a process varies with time, from the start of heating until the temperature stabilises around the set point.

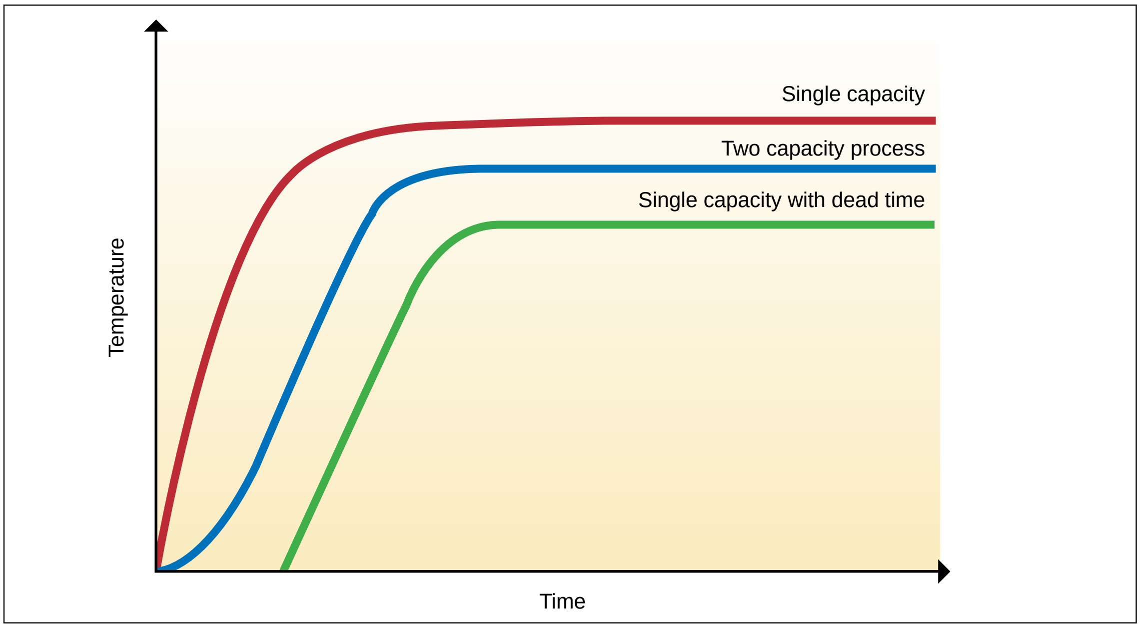


Fig 27 Process reaction curves

The process reaction curve will help to answer the following questions:

- Is the process easy or difficult to control?
- Is the process ***single*** or ***multi-capacity***? (i.e. what are the heat sinks and how many?)
- What is the burner energy input required to satisfy process heat requirements?
- Are the current burners undersized or oversized? (Oversized burners may create control instability and undersized burners are slow to respond.)
- Is the process and furnace thermal mass large or small?

In the case of multi-capacity systems, the interpretation of the control requirements can be particularly complex and should be discussed with suppliers of burners and controls. For new processes where there is little experience of the process reaction curve, the use of mathematical and physical modelling techniques to predict behaviour may be the most appropriate course of action.

7.8 Control Parameters

The chief parameters to be considered in burner control are temperature, rate of heat input, combustion efficiency, and safety. Temperature and rate of heat input are closely related to furnace control, as the burner is the prime means of influencing these aspects.

7.9 Furnace Control Parameters

The main control parameters on modern furnaces are:

- temperature;
- time;
- pressure.

Obviously, close control of the time cycle and temperature conditions is of major importance. Manual control by visual observation is subject to wide variance according to individual operators' interpretation. This method is no longer considered suitable in modern furnaces due to the likelihood of excessive fuel consumption, and possible product damage, resulting from over- or underheating, or excessive oxidation. Therefore, automatic time and temperature controls are essential for optimum furnace operation. Such controls vary widely in sophistication, ranging from simple on/off controllers, to fully modulating controls with

self-tuning features. Where specific rates of heating and/or cooling are important, then programmable temperature controllers may be used to control the furnace to a predetermined time/temperature schedule.

Good working practice requires furnace pressure to be slightly higher than atmospheric. Negative pressure conditions within the furnace may lead to inleakage of cold air through door seals and other openings. The result is a loss in furnace efficiency through cooling of the furnace atmosphere, the creation of cold spots, increased waste gas losses, and increased possibility of damage to stock through excessive oxidation. However, excessive pressure can retard combustion development and increase losses through emission of hot gases via furnace openings, and may cause damage to surrounding steelwork and furnace refractories. Optimum furnace pressure is therefore of critical importance and automatic pressure controls are considered to be an essential part of any furnace control system. The pressure within the furnace varies from the hearth to the roof, due to the buoyancy of the hot gases. Usually, the desired pressure is maintained at stock level, and the pressure transducer should be sited to reflect this. Care should also be taken to ensure that the pressure transducer is not influenced directly by the burners.

Exhaust gas flue areas and stack heights are of crucial importance in furnace pressure control. Fuel changes also influence the pressure within the furnace, as different fuels produce different volumes of flue gas. Burner manufacturers and furnace designers will be able to advise accordingly.

7.10 Combustion Efficiency - Fuel:Air Ratio Control

As discussed previously, the ratio of fuel:air determines the efficiency of combustion (see Fig 28). The ideal situation is stoichiometric combustion. However, in practice, less than perfect mixing of fuel and air, particularly when firing oil, means that a degree of excess air is necessary to achieve complete burnout of the fuel. Too much excess air, however, cools the furnace and reduces efficiency; too little, and unburnt fuel reduces efficiency and may create hazardous

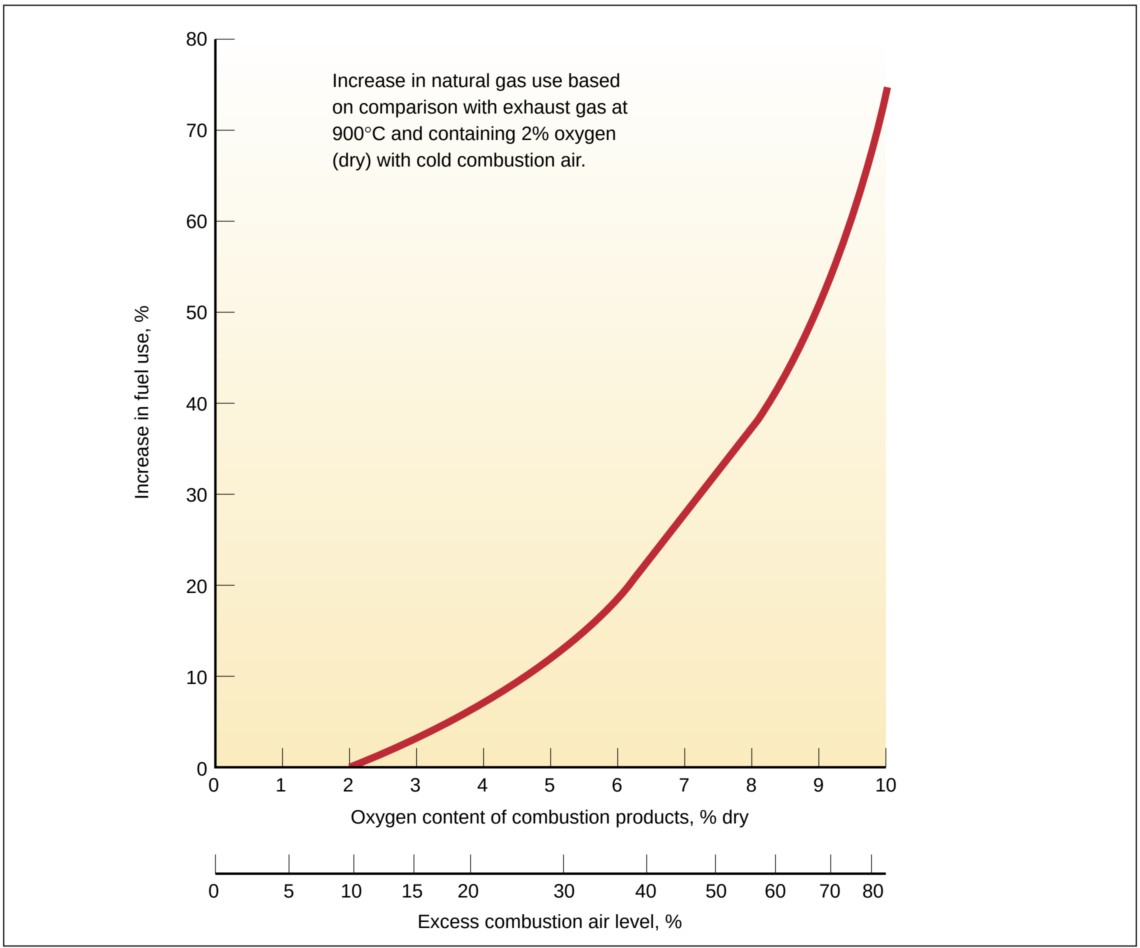


Fig 28 Fuel:air efficiency curve

conditions. In addition to the requirements for maximum energy efficiency, there are also process requirements, specifically the need for an oxidising or reducing atmosphere within the furnace, achieved by varying the fuel:air ratio as necessary. Therefore, correct control of the fuel:air ratio is of critical importance and can be achieved in a number of ways with varying degrees of sophistication and accuracy.

The actual method used to control the fuel:air ratio depends on a number of factors. These include the type of burner, the fuel fired, the turndown ratio, the degree of combustion air preheat, and the process control method employed. The following methods described are commonly used in burner fuel:air ratio control.

7.10.1 *Ganged Valve Assembly*

This is the simplest form of control, where both air and fuel supplies are regulated by a valve or damper in the pipe or duct (Fig 29a). The valve or damper actuators are mechanically linked and driven by a single motor. This is a simple, low-cost method, best suited to ***on/off control*** systems.

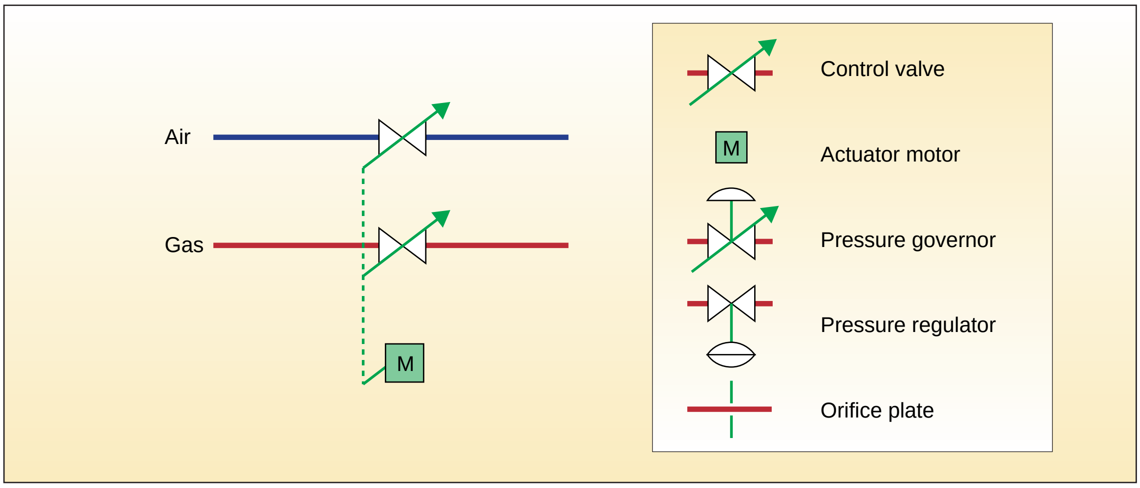


Fig 29a Simple ganged valve assembly

7.10.2 *Cascade Control*

This type of controller relies on the output signal from a differential pressure transducer on an ***orifice plate*** or venturi flow meter situated in either the air supply (an air lead system) or in the fuel supply (a fuel lead system). Any change in the measured flow is countered by an adjustment in the corresponding flow, via a ratio controller. Errors or inaccuracies can be introduced due to the inability of the flow metering devices to operate over a wide range of flows. Where the combustion air is preheated the control signal will require compensation. Orifice plates are a cheaper option than venturi flow meters but cause greater pressure drops in the system (see Fig 29b).

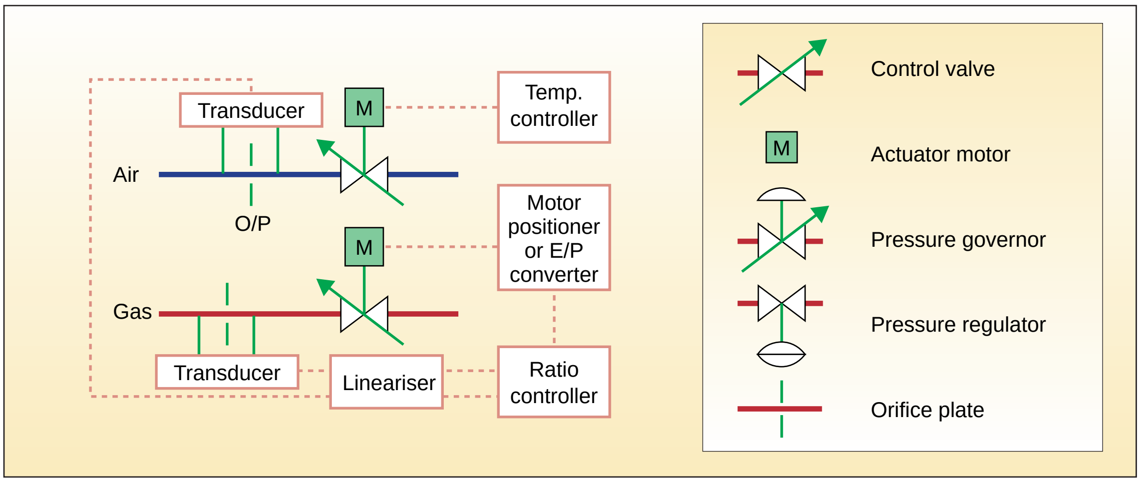


Fig 29b Cascade control (air lead)

7.10.3 *Pressure Divider Technique*

In this system an impulse pressure from the air supply is fed to a zero governor in the gas line. The system is balanced by maintaining the gas pressure as equal to that of the impulsed air pressure. The ratio is thus maintained across a range of flows. Regular maintenance is required and the technique is not suitable for systems using preheated air (see Fig 29c).

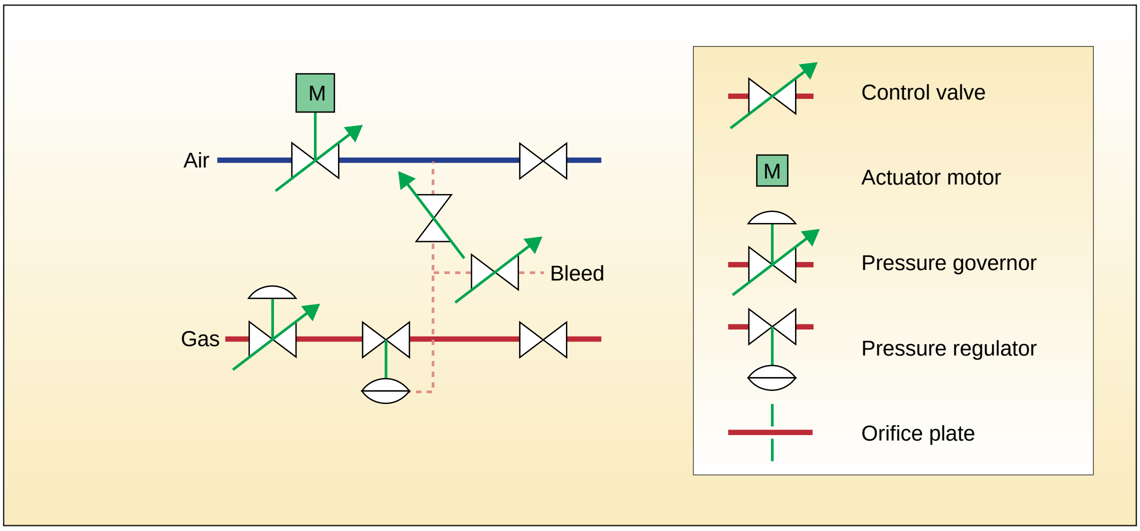


Fig. 29c Pressure divider technique (simple impulse regulator system)

7.10.4 *Multiplying Regulators*

Where systems use preheated air, a multiplying regulator is used to take account of the difference in density between cold and hot air. This measures the flow of cold air and uses an impulse to control the flow of gas accordingly (see Fig 29d).

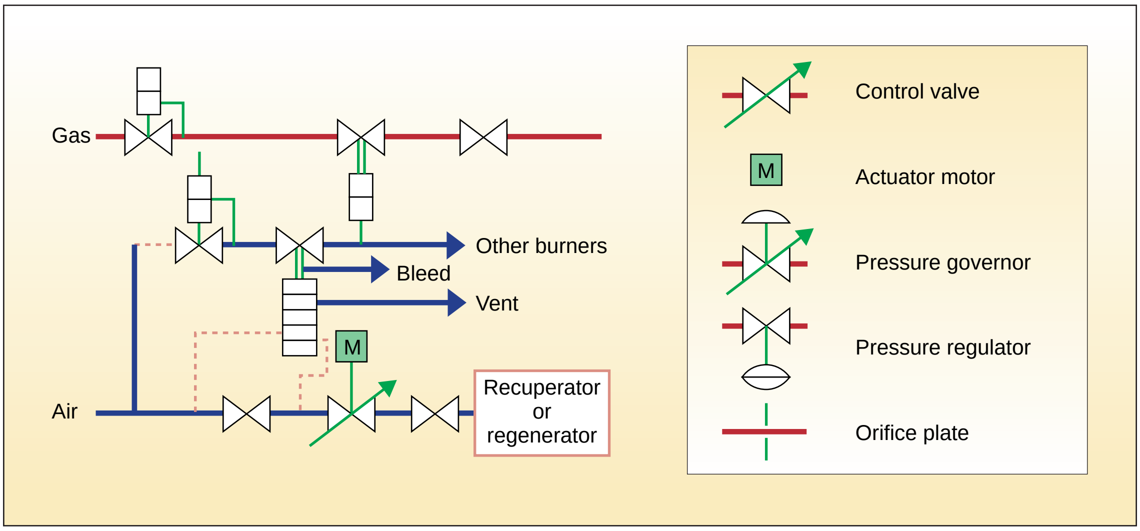


Fig 29d Multiplying regulator system

7.10.5 *Electronic Ratio Control*

Electronic ratio control systems measure the differential pressure across restrictor valves placed in the air and fuel lines. The differential pressures induce a flow in a thermistor block composed of two matched thermistors arranged in a bridge circuit (see Fig 29e). The induced flow heats the thermistors and causes a corresponding change in their electrical resistance. The output from the thermistors is processed by an electronic module that sends a control signal to alter the flow of air in response to a measured change in the flow of fuel, thus maintaining the fuel:air ratio. The advantages of these systems are a rapid response and a high turndown ratio of up to 10:1.

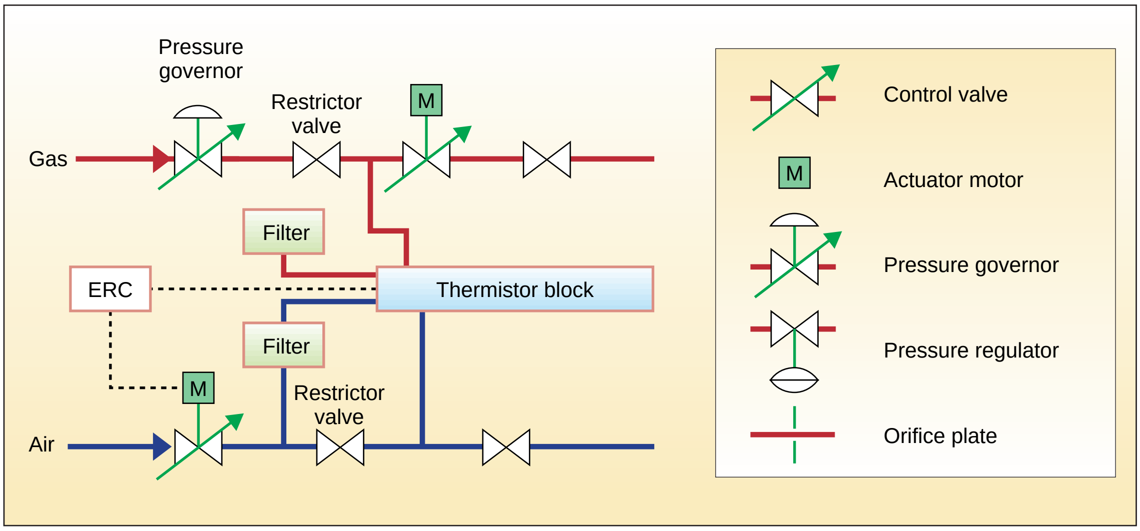


Fig 29e Electronic ratio control

7.10.6 *PLC Control*

In addition to temperature and time functions, PLC controllers can readily handle the function of fuel:air ratio control. Process (e.g. metallurgical) and safety requirements must be taken into account fully when designing a PLC-controlled system.

7.10.7 *Oxygen Trim Control*

The methods of controlling fuel:air ratio described above rely on an initial set-up, usually carried out during commissioning, together with periodic testing and re-adjustment during routine maintenance. Set-up involves the use of some form of portable instrument to monitor oxygen levels in the flue gas, and adjustment of valve or damper linkages or set points as necessary.

Oxygen trim systems are a means of controlling fuel:air ratio on a real-time basis. They have already been extensively implemented in the boiler market with successful results and are now being implemented in furnace control applications.

The system uses an *in situ* ***oxygen probe,*** usually a zirconia-based oxygen-measuring cell and thermocouple, and an electronic analyser/controller. Together they provide a control output to the air or fuel flow controller. The probe is mounted at a representative position in the flue gas path. Care must be taken to ensure that the probe is sited well away from burner flame paths. The probe is connected to the analyser which calculates the oxygen concentration in the flue gases. The control output is passed to a signal limiter containing the desired set point and then to a ratio controller that acts on the fuel and air flow control mechanisms to maintain the desired ratio. The signal is usually limited to within plus or minus 10% of the desired set point.

The zirconia probe offers advantages in that it requires no calibration or maintenance. Probe life should be a minimum of six months in normal applications. Savings of up to 5% in fuel consumption can be expected at attractive paybacks.

Case study: Installation of oxygen trim control on a steel reheat furnace

In this case study, five zirconia-based oxygen probes were installed in the roof of a steel reheat furnace at Rotherham Engineering Steels' Roundwood Coil Bar Mill. The probes were linked to an oxygen analyser, signal processor, and ratio controller. The system was used to trim the fuel:air ratio to the burners, thus maintaining a preset oxygen level in the combustion products. The prime motivation for the project was to increase the product quality, but energy savings of 2% were initially achieved and were expected to rise to 5% with further adjustment.

7.11 The Use of Variable Speed Drives for Combustion Air Supply

Combustion air is traditionally supplied to the burner by a fan or blower. The volume supplied, and hence the fuel:air ratio achieved, is usually regulated by means of a damper or butterfly valve located in the air duct or pipe between the fan and burner. While this is a reasonably effective means of regulating the flow, it is highly inefficient in terms of the electricity consumed by the fan or blower motor. ***Variable speed drives (VSDs)*** can be used to vary the speed of the motor in response to the air demand, with a significant reduction in electricity consumption and cost. When combined with an oxygen trim system providing a control output signal, further significant benefits may be available in terms of improved combustion efficiency through very precise control of fuel:air ratio. Although not yet implemented practically, these types of system may be further developed in future.

For further information on the implementation of VSD technology, see Good Practice Guide 2, *Energy savings with electric motors and drives*, and Good Practice Guide 14, *Retrofitting AC variable speed drives*. The successful installation of VSDs on combustion air fan motors in high-temperature process industries is described in Good Practice Case Studies 115, *Variable speed drives on a large continuous furnace combustion air fan* and 125, *Variable speed drives on a batch furnace combustion air fan*.

7.12 Relative Costs

Effective control should aim to: optimise the energy content of the fuel; minimise the time required to achieve the desired temperature; maintain the temperature at the lowest value consistent with process requirements, with minimum cycling about the set point; optimise the process duration. Any failure to meet the above criteria leads to higher energy use and, therefore, wasted money.

In conventional air:fuel ratio control, the oxygen required for combustion is provided by maintaining a fixed ratio between the fuel input and the amount of air delivered for combustion purposes. The ratio is adjusted manually to allow for different rates of heat input and temperature requirements. To avoid potential problems, the air:fuel ratio is normally set at the upper limit of the tolerable range for a specific product type. This leads to greater volumes of air than are necessary being admitted to the furnace, resulting in cooling of the furnace and greater quantities of waste heat being exhausted from the furnace. The use of oxygen trim control allows a lower air:fuel ratio to be employed and continually adjusted as the measured volume of oxygen in the combustion products changes.

Table 5 uses this example to indicate the likely cost savings achievable by the installation of oxygen trim control. At two percent saving, payback would be achieved in less than nine months, making oxygen control clearly a worthwhile investment. As the original project was carried out in 1989, cost data have been updated to 1998 levels.

Table 5 Cost analysis for oxygen trim control

Costs		**Manual control**	**Oxygen trim (% saving)**			
			2%	**3%**	**4%**	**5%**
Installation of oxygen control	(£)		35,000	35,000	35,000	35,000
Manpower costs	(£)	20,000	10,000	10,000	10,000	10,000
Annual maintenance cost	(£)	1,000	5,000	5,000	5,000	5,000
Fuel consumption	(£/a)	1,950,750	1,911,735	1,892,228	1,872,720	1,853,213
Lifetime	(Yrs)	6	6	6	6	6
Annual fuel and maintenance cost	(£)	1,971,750	1,926,735	1,907,228	1,887,720	1,868,213
Capital cost	**(£)**	**0**	**35,000**	**35,000**	**35,000**	**35,000**
Saving per annum	**(£)**	**0**	**45,015**	**64,523**	**84,030**	**103,538**
Present value saving						
Year	Discount factor					
Year 0	1.0000	0	-35,000	-35,000	-35,000	-35,000
Year 1	0.9091		40,923	58,657	76,392	94,126
Year 2	0.8264		37,200	53,321	69,442	85,563
Year 3	0.7513		33,819	48,474	63,129	77,785
Year 4	0.6830		30,744	44,067	57,390	70,714
Year 5	0.6209		27,949	40,061	52,173	64,285
Year 6	0.5644		20,997	36,419	47,430	58,441
Net present value	**(£)**		**156,633**	**246,000**	**330,957**	**415,914**
Simple payback	**(Yrs)**		**0.78**	**0.54**	**0.42**	**0.34**
Internal rate of return	**(%)**		**128%**	**185%**	**240%**	**296%**

Fuel cost assumptions: Gas oil - £3.18/GJ Gas - £2.55/GJ

Fig 30 shows the decision route taken when considering the benefits of oxygen trim control.

7.13 Supply, Installation and Commissioning

Most burner manufacturers will supply controls to accompany their products. Although some manufacturers may not make all the necessary components themselves, most will assemble a control panel to their own or clients' specifications using the appropriate outsourced hardware, and will carry out all installation and commissioning work as required. Many manufacturers may prefer to commission their own equipment, taking the view that this minimises the likelihood of problems in the future and makes their rectification more straightforward if they do occur.

The alternative approach is to design the control system in-house and have a specialist panel builder build, install, and commission the system. Burner manufacturers will supply all necessary control details to accompany their product and it is strongly recommended that their advice is sought if this is the chosen route.

7.14 Control Maintenance and Calibration

Regular servicing and calibration of control systems are as important as burner servicing and essential to ensure a safe, reliable, efficient, and clean combustion system. It is recommended that controls are checked and serviced on a biannual or annual basis. Consumable items, e.g. flame ionisation detectors, should be inspected at least monthly and replaced as required. Inspection and service frequencies may vary according to the type of fuel fired and the particular characteristics of the burner equipment and furnace in question. It is strongly recommended that manufacturers' and suppliers' service and inspection intervals are observed in all cases.

Control servicing should include recalibration of measuring devices and checking and adjustment of control rods and linkages where appropriate. Flame failure and safety systems must be tested to ensure fail-safe operation under all conditions in accordance with British Standards.

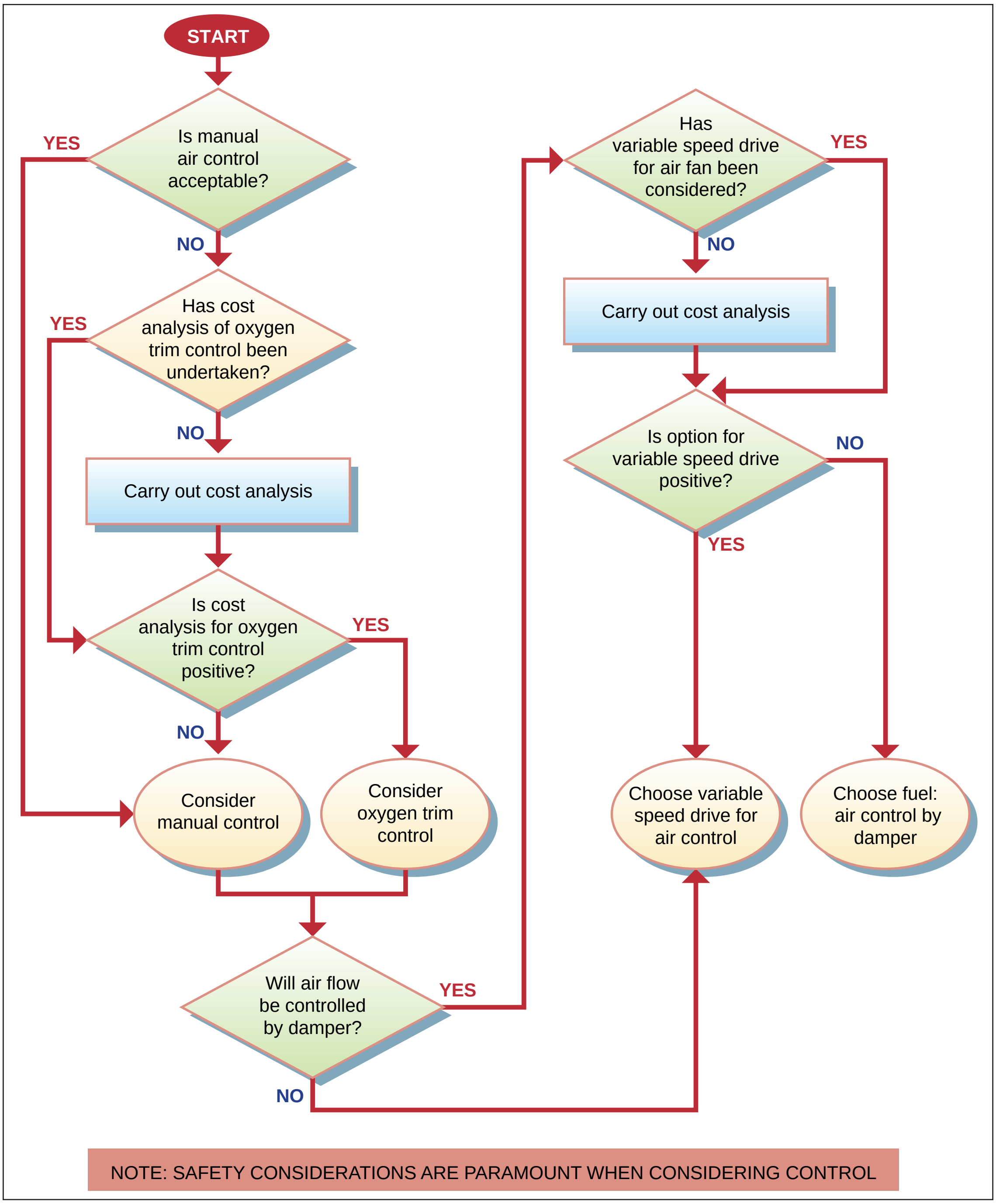


Fig 30 Application guide for fuel:air ratio control

8. FORMULATING AN ACTION PLAN - THE KEY QUESTIONS TO BE ASKED

This Section provides information on factors that should be considered for specific courses of action, e.g. the selection of burners or controls. It is not intended to be exhaustive as there are several organisations that can offer comprehensive advice, or information, on these topics. These include equipment suppliers, installers, energy efficiency consultants, and the Energy Helpline (0541 542 541). It is recommended that appropriate organisations are consulted.

In most cases, the information presented below is discussed in detail in the body of this Guide.

8.1 To Improve the Efficiency of Burners

The assessment of performance levels is a key factor in improving the efficiency of burners. Steps to achieve this are listed below:

1. Analyse any historical energy and production data available:

- compare with other similar units and with the design specification;
- construct an energy balance;
- check the function and accuracy of all controllers and the location of probes and thermocouples.

2. Examine:

- temperature curves;
- stock temperature;
- temperature range;
- degree of cycling;
- temperature of exhaust;
- time to reach operating temperature;
- light-up procedure.

Any exceptionally high temperatures or deviations from the set point should be fully examined and appropriate experts consulted.

Check that the most appropriate temperature control technique is being used.

3. Analyse combustion gases in exhaust:

- If oxygen is high:
  - ➩ look for air infiltration;
  - ➩ examine fuel:air ratio.

- If combustion is incomplete, check:
  - ➩ fuel:air ratio;
  - ➩ that fuel atomisation is satisfactory;
  - ➩ that there is adequate air/fuel mixing;
  - ➩ the viability of oxygen trim control.

Oxygen levels should be between 2 and 3% (dry basis) in the exhaust gas.

4. Examine burner characteristics:

- rating of burner(s) against specification;
- air preheat temperature (where appropriate);
- frequency of cycling during operation.

8.2 Selection of Burners

When considering the selection of burners for a new or existing furnace the following factors should be included:

1. Define or reassess the process requirements:

- temperature of operation;
- time at temperature;
- acceptable temperature span;
- rate of heating;
- required drop-out temperature;
- temperature uniformity;
- throughput/loading;
- schedule of use (intermittent or continuous);
- output (continuous or batch).

2. Consider constraints:

- identify location;
- available capital;
- purchase cost;
- atmospheric requirements;
- frequency, cost, and ease of maintenance.

3. Consider options:

- single or multiple burner installation;
- cold- or hot-air burner;
- remote or integral heat recovery;
- recuperative or regenerative burner;
- expenditure.

Use the form in Fig 7 to collate the necessary information prior to approaching burner suppliers.

8.3 Selection of Controls

Selection of the most appropriate controls for the burner is based on the following: ensuring the attainment of the correct operating temperature; minimisation of the deviation about the set point; controlling the rate of heat input; optimising combustion efficiency.

Safety controls will be an integral feature of the burner and are not optional.

1. For selection of temperature control, identify:

- temperature of operation;
- temperature spread;
- required temperature uniformity of stock and furnace;
- whether the process is easy or difficult to control (if possible produce process reaction curve to determine this).

2. Identify:

- frequency of light-up;
- continuous operation or batch rate of heat-up;
- variation in hearth loading;
- capital available;
- complete analysis of costs for various options.

8.4 Combustion Control

Key factors to be examined when ensuring optimum combustion efficiency:
- analyse variability of oxygen found in exhaust gases;
- consider automatic proposed fuel:air ratio control;
- consider variable speed drive fan for control of combustion air;
- is oxygen trim control cost effective in this application?

8.5 Further Reading

British Standard BS EN 746-2:1997. *Industrial Thermoprocessing Equipment, Part 2. Safety Requirements for Combustion and Fuel Handling Systems.* ISBN 0 580 28104 3.
Available from The Stationery Shop's British Standards Order Line. Tel: 0171 404 1213 Fax: 0171 242 3315.

Health and Safety Executive Guidelines. *Programmable Electronic Systems in Safety-Related Applications.* ISBN 0 717 61278 3.
Available from HSE Books. Tel: 01787 881165 Fax: 01787 313995.

Secretary of State's Guidance Note PG 1/3 (95), August 1995. *Boilers and Furnaces, 20 - 50 MW Net Rated Thermal Input.* ISBN 0 11 753146 4.
Available from The Stationery Office Shop. Tel: 0171 873 9090.

Chief Inspector's Guidance Note S2 1.01, November 1995. *Combustion Processes: Large Boilers and Furnaces 50 MW(th) and over.* ISBN 0 11 753206 1.
Available from The Stationery Office Shop. Tel: 0171 873 9090.

8.6 Useful Addresses and Contacts

Energy Helpline (part of the Energy Efficiency Best Practice Programme)
Tel: 0541 542 541 (telephone charges apply)

Environmental Helpline (part of the Environmental Technology Best Practice Programme)
Tel: 0800 585794 (freephone)

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA

Tel: 01235 436747 Fax: 01235 433066
E-mail: etsuenq@aeat.co.uk

The Combustion Engineering Association
1a Clarke Street
Ely Bridge
Cardiff
CF5 5AL

Tel: 01222 555833   Fax: 01222 553181

British Combustion Engineering Manufacturers' Association
The Fernery
Market Place
Midhurst
West Sussex
GU29 9DP

Tel: 01730 812782   Fax: 01730 813366

8.7 Suppliers of Burners and Control Equipment and Related Services

The following list of suppliers is intended to help potential users in finding suitable equipment and in obtaining more detailed information. The list is not exhaustive and has been compiled from information currently available to ETSU. The listing of a supplier of goods or services does not constitute an endorsement of its competence by the Department of the Environment, Transport and the Regions, and neither does the omission of a supplier discriminate against its competence.

The names and addresses of other suppliers may be found in commercially available trade directories or obtained from trade associations.

8.7.1 Burner Manufacturers and Suppliers

CGE Ltd
Peel Road, West Pimbo, Skelmersdale, Lancashire, WN8 9PT
Tel: 01695 727441

Eurograde Plant Ltd
Unit 3, Viscount Industrial Estate, Horton Road, Poyle, Colnbrook, Berkshire, SL3 0DF
Tel: 01753 681890

Fairbank Brierly Ltd
Valley Works, Ribble Street, Keighley, West Yorkshire, BD21 4LP
Tel: 01535 611272

Hirt Combustion Engineers
Woodford Green Works, Leslie Road, Woodford Park Ind. Estate, Winsford, Cheshire, SW7 2JE
Tel: 01606 861366

Hotwork Development Ltd
Bretton Street, Savile Town, Dewsbury, West Yorkshire, WF12 9DB
Tel: 01924 465272

Laidlaw Drew Ltd
1 Lister Road, Kirkton Campus, Livingston, Scotland, EH54 7BL
Tel: 01506 416666

Mont Selas (a division of Hunt Thermal Ltd)
Astley Street, Dukinfield, Cheshire, SK16 4QT
Tel: 0161 655 1034

Nu-Way Ltd
PO Box 1, Vines Lane, Droitwich, Worcestershire, WR9 8NA
Tel: 01905 794331

Stirling Process Engineering Ltd
Brunel Road, Rabans Lane, Aylesbury, Buckinghamshire, HP19 3SS
Tel: 01296 87171

Stordy Combustion Engineering Ltd
Heathmill Road, Wombourne, Wolverhampton, West Midlands, WV5 8BD
Tel: 01902 897654

Wellman Furnaces Ltd
Cornwall Road, Smethwick, Warley, West Midlands, B66 2LB
Tel: 0121 358 3151

8.7.2 *Research Organisations*

British Steel PLC
Swinden Technology Centre
Moorgate
Rotherham
South Yorkshire
S60 3AR

Tel: 01709 820166

BG Technology
Gas Research and Technology Centre
Ashby Road
Loughborough
LE11 3GR

Tel: 01509 282000

8.7.3 *Modelling Contractors*

The University of Leeds
Department of Fuel and Energy
Leeds
LS2 9JT

Tel: 0113 233 2508

BG Technology
Gas Research and Technology Centre
Ashby Road
Loughborough
LE11 3GR

Tel: 01509 282000

GLOSSARY

Atomisation

Atomising (burner)	Oil needs to be broken down into droplets to facilitate vaporisation and combustion. Atomising burners are classified according to the source of energy used to disintegrate the fuel.
Blast atomiser (twin-fluid)	These operate at low, medium, or high pressure; steam or air and oil impinge, either within (internal mixing) or at the outlet (external mixing) of the burner. • *Low pressure* - uses air at 105 to 115 kPa (15 to 17 psi) as the atomising medium. A large proportion (sometimes all) of the combustion air is used as the atomising medium. Turndown ratio is between 2:1 and 5:1. • *Medium pressure* - uses air at 230 to 300 kPa (33 to 44 psi). Less than 10% of the combustion air is used to atomise the fuel. Turndown ratios of 10:1 can be obtained. • *High pressure* - uses air or steam at >300 kPa (44 psi). High-pressure steam burners are used only when a large amount of dry steam is available.
Pressure jet atomiser	Oil is pumped at high pressure (700 to 3,500 kPa, or 100 to 500 psi) through a fine nozzle to produce a spray of droplets. Heavy fuel oil may need to be preheated to reduce the viscosity to an acceptable level.
Rotating cup atomiser	Oil flows through a central pipe to the inner surface of a revolving, hollow, tapered cup. It spreads over the surface and is thrown off the periphery of the free end by centrifugal force.
Steam jet	This is a blast (twin-fluid) atomiser using steam at high pressure. Between 0.3 and 0.5 kg of steam per kg of oil are required.
Burner	A means of combusting fossil fuel under control, to enable the introduction of heat into a furnace.
Burner quarls	Refractory components surrounding the burner nozzle.
Calorific value (CV)	The quantity of heat liberated when a fuel is burned. • Gross CV includes the heat liberated when water vapour condenses to liquid at room temperature. • Net CV is the value when, under practical conditions, the combustion gases are not cooled sufficiently to liberate the latent heat of water.
CO	Carbon monoxide, one of the intermediate products of combustion of carbon. Analysis of levels of CO in flue gases gives an indication of the level of incomplete combustion.
CO_2	Carbon dioxide, a product of complete combustion of carbon.

Combustion — A rapid chemical reaction between the combustibles in the fuel and oxygen in the air with liberation of heat. In gas and liquid fuels, carbon and hydrogen constitute the combustibles.

Combustion air — Air that contains the oxygen needed to burn the fuel. Identified as either primary air (introduced at the point of combustion), or secondary or tertiary air (introduced to the flame or elsewhere in the furnace).

Combustion efficiency — The percentage of heat released that is put to use compared to the total heat energy in the fuel.

Conduction — When a temperature gradient exists in a stationary medium, heat is transferred from the hot to the cold region by conduction.

Controlled atmosphere — A specific type of atmosphere can be created within a furnace to satisfy the requirements of the product being treated, e.g. oxidising or reducing atmospheres may be created or avoided, or certain levels of humidity achieved. Radiant tube or panel burners are often used to separate the combustion products from the stock.

Controls

Set point — The desired process condition, e.g. temperature.

Error — The deviation from the set point.

Dead time — The time delay between elements of a control loop.

On/off control — The simplest form of temperature control. Normally the unit is fully on or fully off. It is very difficult to achieve a fixed set point without a wide under- and overshoot of the set point temperature.

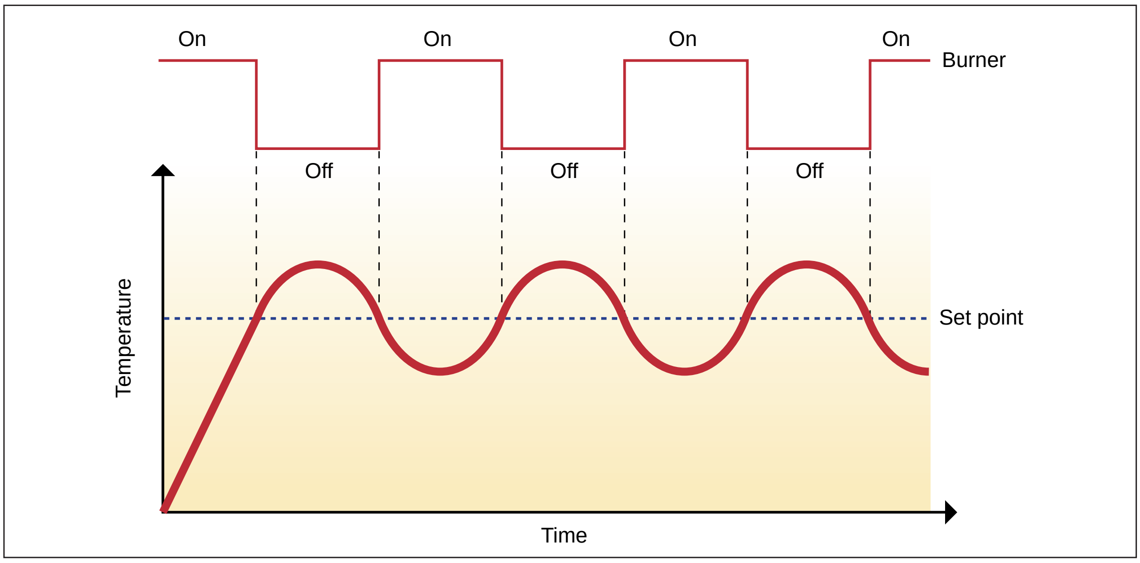


Fig 31 Time-temperature curve for simple on/off controller

Proportional control — This continuously adjusts heat input to the process in linear proportion to the error, thus maintaining a stable temperature. As shown in Fig 32, control is effected over a temperature band above and below the set point (called the proportional band).

The energy input varies from 0-100% over the proportional band. The energy input is zero when the temperature crosses the upper limit of the proportional band and 100% when the temperature crosses the lower limit.

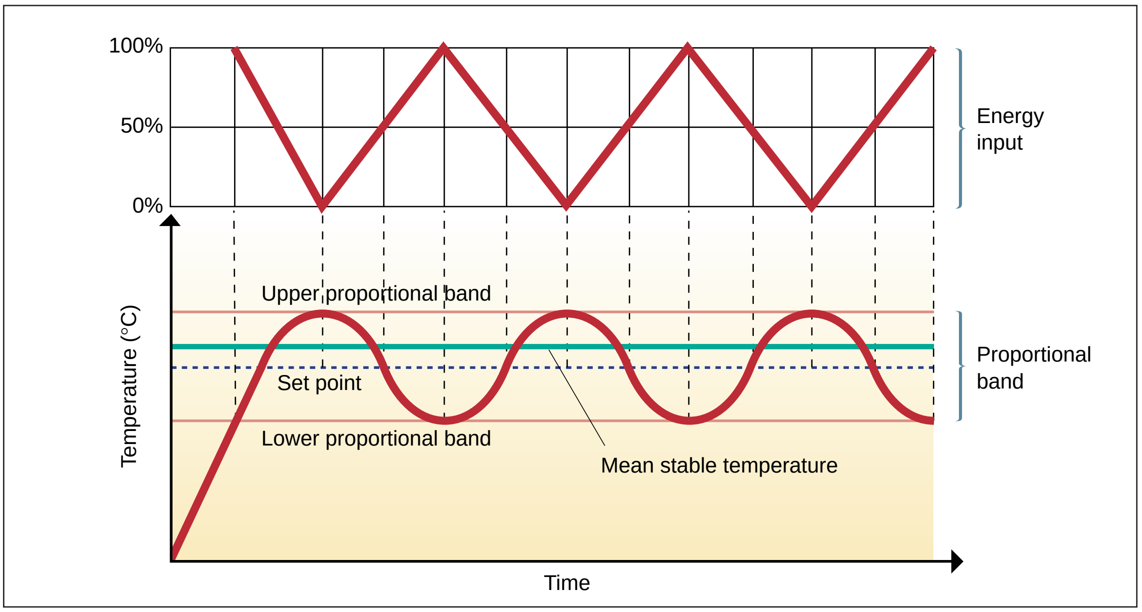


Fig 32 Time-temperature curve for simple proportional controller

The problem with proportional control is that at set point temperature the energy input is 50% of that available and it is rare that the heat input necessary to maintain the set point temperature is 50% of the maximum. Consequently the temperature will increase or decrease from set point, varying the energy input until an equilibrium condition is reached (Fig 33a). The difference between the equilibrium temperature and the set point temperature is known as the ***offset***.

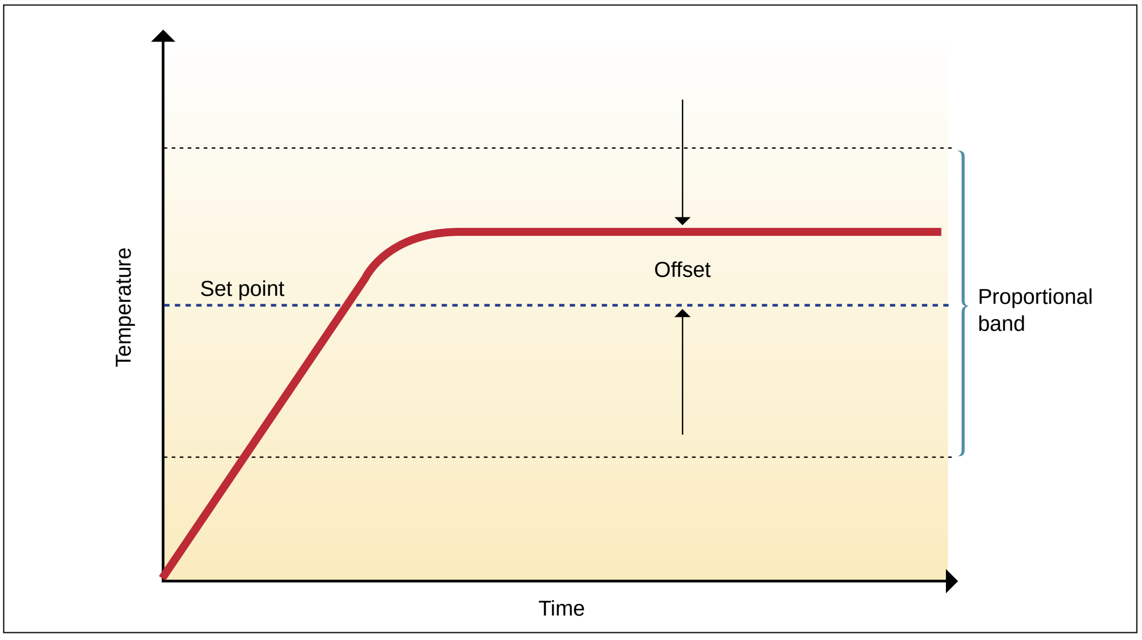


Fig 33a Time-temperature curve showing temperature offset

The set point temperature can be achieved by moving the proportional band up or down. In the case of Fig 33b moving the band downwards. The offset can be moved either manually or automatically. Manual adjustment can only be done by slowly adjusting the position of the proportional band until the heat input matches the process heat demand. This is a time consuming process and would need to be done for any changes in the process heat requirements. It is therefore better achieved automatically.

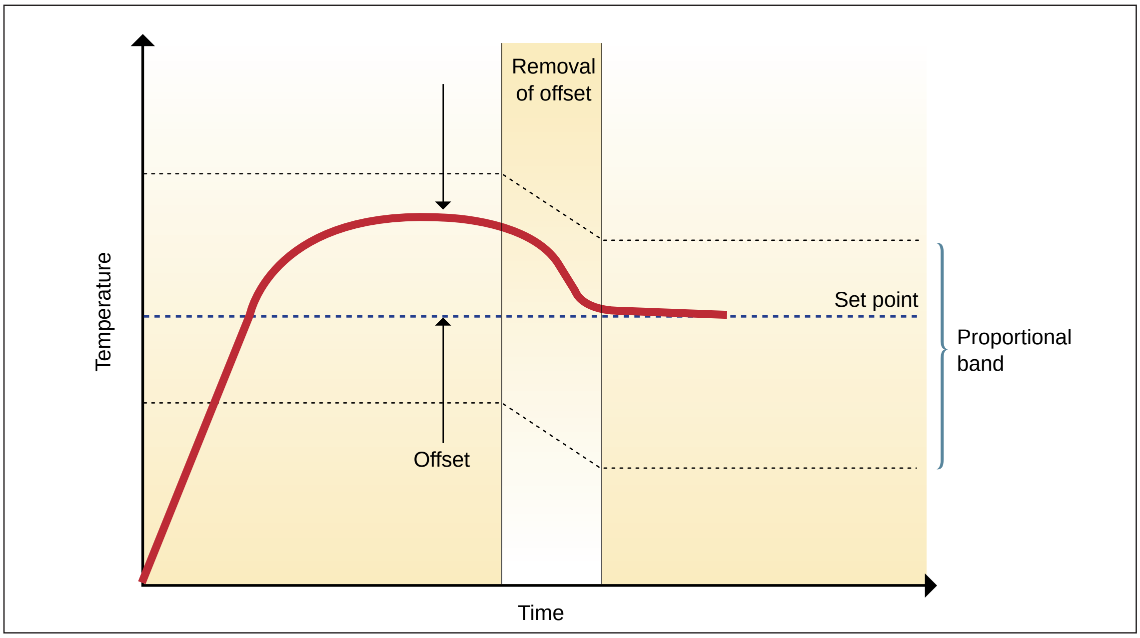


Fig 33b Time-temperature curve showing removal of temperature offset

Integral control

The controller output is proportional to the integral of the deviation from the set point (see Fig 31). There is no offset with this type of control as the output keeps changing as long as the deviation persists.

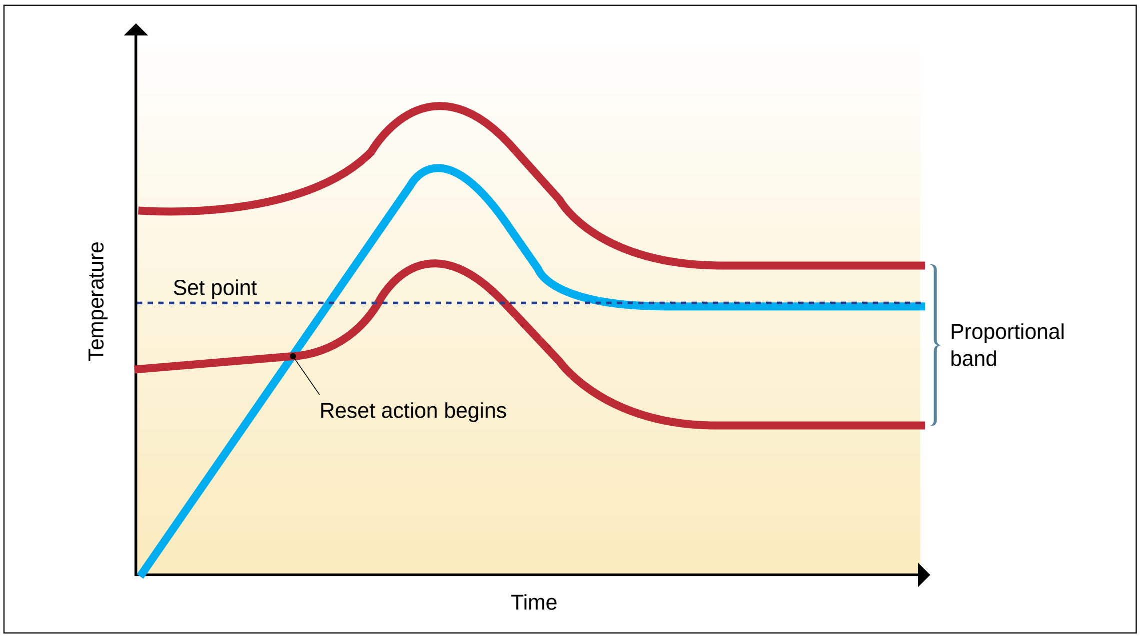


Fig 34 Time-temperature curve showing effect of proportional plus integral action

Derivative control	Derivative action is often added to proportional control to improve the response of slow systems. The derivative function provides the controller with the ability to shift the proportional band either up or down to compensate for rapidly changing temperature. The amount of shift is proportional to the temperature change.
PID control	Proportional and integral and derivative control. This is a three-mode controller combining all three actions and is usually required to control difficult processes.
Convection	Heat transfer that occurs between a surface and a moving fluid when they are at different temperatures.
Drive	The thrust, or velocity, of the hot gases directed into the furnace. The higher the velocity of the burner jet the better the temperature uniformity and the rate of convective heat transfer.
Dual-fuel burners	These have the facility to burn either oil or gas, or both fuels at the same time. They are useful when there are uncertainties in terms of lower cost fuel supplies (e.g. interruptible gas).
Excess air	The provision of combustion air in greater quantities than is required to provide sufficient oxygen for stoichiometric combustion. Excess air produces an oxidising atmosphere in the furnace.
Excess fuel	A greater proportion of fuel than oxygen available to burn it; results in smoke and pollutants.
Eductor	A device that causes movement in a secondary fluid resulting from entrainment brought about by movement in a primary fluid. Used in self-recuperative burner systems to draw flue gases through the burner body.
Flame detection	Fuel must be ignited immediately it leaves the burner outlet; otherwise, it can lead to a major fire or explosion. For this reason, flame detection sensors are used to confirm that the fuel has ignited. Techniques include monitoring temperature, radiation, and ionisation.
Flame shape	Burner design determines the relative velocity of the fuel and air streams and dictates the flame shape. Good mixing, produced by a high degree of turbulence and higher velocity, produces a short, squat flame; poor mixing and lower velocity produce lazy, flickering flames.
Flame stability	A flame is stable if it is moving towards the burner at the same speed as the fuel/air mixture is leaving the burner. If the mixture speed is higher than the flame speed, the flame will be pushed away from the burner and may go out (lift off). If the mixture speed is lower than the flame speed, the flame may ‘flash back’ through the burner.

Flashback	This occurs when the rate at which fuel is burned in the body of the nozzle is higher than the rate at which it is delivered to the nozzle. This is an unsafe combustion and is avoided by careful adjustment of fuel flow rate and the use of flame arrestors.
Flue gases	The exhaust gases leaving the furnace.
Fuel:air ratio	For maximum efficiency the combustion air should be limited to that necessary for complete combustion of the fuel. Because of less than perfect mixing of fuel and air, excess air is normally provided. See also excess air/excess fuel, above, lean mixture, rich mixture.
High-velocity (burner)	A burner capable of achieving high rates of heat input and providing strong circulation to the furnace atmosphere, thus assuring good rates of heat transfer and uniform temperature distribution in the furnace.
Ignition point	Mixtures of fuel and air will not normally burn at room temperature because they are too cold. They require heating to a temperature called the 'ignition point', which varies with the type of fuel and the fuel:air ratio.
Impulse fired (burner)	This is a variant of the regenerative burner where the burners operate at zero or maximum thermal input. Each burner fires alternately for 15 seconds. The 'off' period between reversal varies, depending on the heat input requirement.
Inferred efficiency	This is obtained by subtracting calculated efficiency losses from 100%.
Interruptible tariff	An energy supply tariff that enables lower cost rates for supply of electricity and natural gas (providing the supply can be turned off at times of high demand).
Lean mixture	A mix of fuel and air with the air in excess of combustion requirements.
Lift off	This occurs when the rate at which fuel is burned is less than the rate at which it is delivered to the nozzle, causing the flame to separate from the burner nozzle. Lift off can lead to flame out.
Low-NO_x burners	Because energy use is becoming more efficient, burners are operating at increasing flame temperatures. This can lead to combustion products with higher levels of oxides of nitrogen (NO_x), which have an adverse environmental impact. Burners that maintain high levels of efficiency while reducing levels of NO_x emissions are now being developed.
Luminous flame	A yellow flame, rich in suspended solid particles, indicative of incomplete combustion. Although of lower combustion efficiency, a luminous flame is more effective in terms of heat transfer by radiation.
Mathematical modelling	This involves using a mathematical representation that describes the process under consideration. The magnitude of the operation's parameters can be adjusted to allow the influence of these changes to be determined.

Measurement	The list below describes some of the most suitable methods of measuring relevant parameters.
Orifice plate	A plate (with a central hole) that is fitted into a pipeline. This generates a differential pressure that can be used to determine the flow rate of the gas stream.
Pitot tube	A tube that is inserted into the gas stream and used to determine the velocity of the gas stream by measuring the static and dynamic pressures.
Pyrometer	An instrument that determines temperature by measuring the wavelength intensity of the hot body. A non-contact method for high temperatures.
Suction pyrometer	A variation of the pyrometer; hot gases are drawn over a shielded thermocouple, thus eliminating the effects of radiant heat transfer.
Temperature measurement	Involves monitoring the change produced by change in temperature. This may be expansion, change of state, electrical effects, or wave transmission. Temperature range, response time, required accuracy, spatial resolution, and application determine the choice of temperature-measuring instruments.
Thermocouple	Measures the voltage (varies with temperature) produced at the junction of two dissimilar metals.
Venturi	A flow restriction fitted into the gas stream, thereby creating a differential pressure that can be used to measure flow rate.
Multi-capacity process	This involves a complex relationship between differing rates of heat input, transfer, and heat capacity.
NO_x	The combined oxides of nitrogen: principally nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O). NO_x is a major source of pollution: first, in terms of photochemical smog and acid rain, and second, as a contributor to the greenhouse effect.
Nozzle mix	Fuel and air are brought together at the burner nozzle to ensure good fuel/air mixing and minimise unburned fuel.
Oxygen probe	Instrument for determining the concentration of oxygen in a gas stream, using in line or sampling techniques; sometimes referred to as a zirconia probe.
Oxygen trim controller	A control system involving measurement of the oxygen concentration of the combustion products and adjustment or ‘trimming’ of the fuel:air ratio.
Preheat	This involves raising the temperature of the stock or combustion air (normally by using exhaust gases as they leave the furnace). It ensures that the waste heat finally discarded to the atmosphere is of low grade and reduces the heat required from the primary heat source.

Premix Fuel and air are mixed in the body of the burner, prior to combustion.

Radiant tube The burner is contained in a closed tube and the combustion products pass through a heat exchanger to heat the incoming air. The fuel and air are introduced at the same end that the combustion products leave. Radiant tubes are often used in controlled atmosphere furnaces and for tank heating and also as immersion heaters in certain non-ferrous metal processes.

Radiation (thermal) Electromagnetic wave energy emitted by the surface of a body at a finite temperature. For two adjacent surfaces at different temperatures there is a net heat transfer by radiation, although convection may also play a part.

Recuperator A heat exchanger that allows the combustion air to be preheated by the hot exhaust gases. The recuperator may be integral with the body of the burner (self-recuperative) or outside the furnace and separated from the burner (remote recuperator).

Redwood seconds A measure of the viscosity of a liquid, based on an experimental technique that requires measurement of the time taken for a fixed volume of liquid to flow, under gravity, through an orifice of fixed dimensions.

Regenerative burner A regenerative burner system consists of a pair of burners, each with its own integral regeneration chamber and a facility for reversing flow. While one burner fires using air fed to the base of its regenerator the other burner acts as an exhaust port drawing off waste gas, thereby heating its regenerator. When this regenerator is sufficiently charged with heat the flow is reversed and air is preheated for combustion in this burner.

Regenerator A means of recovering heat, usually from the exhausted products of combustion. Hot gases are passed over a bed of heat-retaining material such as refractory brickwork. Once heated to the optimum temperature, the exhaust gas is redirected to heat the second chamber of the regenerator. Cold air is then passed through the first chamber to recover the heat in the refractory, prior to being used for combustion of the fuel. The two chambers are continuously cycled during use.

Retrofit Installation of additional equipment or replacement of current equipment on existing units.

Rich mixture A mix of fuel and air with insufficient air for complete combustion.

Secondary air Air that is introduced with the flame, in addition to the primary combustion air, to ensure complete combustion or an oxidising atmosphere.

Self-recuperative (burner) This burner has an integral heat exchanger that allows the combustion products to heat the incoming air and thus improve the efficiency of fuel use.

Single capacity process	This is where the rate of temperature rise is directly proportional to the rate of input.
SO_x	The combined oxides of sulphur: principally sulphur dioxide (SO_2) and sulphur trioxide (SO_3). SO_x is a major cause of acid rain and arises during the combustion of sulphur-containing fuels (mainly oil and coal).
Specific energy consumption (SEC)	The amount of energy required per unit of production.
Stoichiometric combustion	Stoichiometric conditions are met when the volume of oxygen is exactly sufficient to combine chemically with all the combustibles in the fuel. Under practical conditions, perfect mixing of fuel and oxygen is not achievable and excess oxygen or air is required for full combustion of the fuel.
Temperature control	This aims to achieve a set temperature within a stated range. It entails measurement and a feedback mechanism to control the rate of fuel input (automatic or manual).
Turndown (ratio)	The range of input rates within which a burner will operate satisfactorily. Defined as the ratio of maximum to minimum heat input rates. The greater the turndown ratio the better the control.
Variable speed drive (VSD)	A means of controlling the speed of conventional electric motors, with a reduction in power consumed.
Waste heat recovery	The utilisation of heat that would otherwise be lost to the environment.

APPENDIX 1

PRINCIPLES OF COMBUSTION

A1.1 What is Combustion?

Combustion is defined as the rapid chemical reaction of combustible matter with oxygen, with the consequent release of energy, usually in the form of heat. In gaseous and liquid fuels the combustible matter is usually carbon and hydrogen. These do not exist in pure forms, but are generally combined as hydrocarbon compounds. The combustion reactions are complex, involving many intermediate steps and compounds, before the formation of the final products of combustion, chiefly carbon dioxide and water vapour.

A1.2 Fuel:Air Ratio

In ideal combustion, fuel and oxygen are present in exactly the right quantities for complete reaction. This is called ***stoichiometric combustion.*** However, under practical conditions the fuel and oxygen do not mix sufficiently in the time available to ensure complete combustion. Therefore it is normal to introduce a proportion of extra combustion air, called ***excess air.*** Too little excess air may cause inefficiency due to unburned fuel and combustible intermediate compounds leaving the furnace. Too much excess air causes inefficiency because the additional air carries away heat, which should be transferred to the furnace stock, in the flue gases. Analysis of the products of combustion in the flue gases gives vital information on the efficiency of the combustion process.

A1.3 Mixing and Atomisation

Fuel and air must be brought together and mixed in order to react completely. In the case of gaseous fuels this is relatively straightforward. In the case of liquid fuels, however, the fuel must first be broken down into small droplets, which then vaporise and mix with the combustion air. This process is known as ***atomisation.*** Atomisation and mixing are two of the main functions of a burner.

A1.4 Ignition

A mixture of fuel and air will not normally react if mixed together at room temperature and pressure. The temperature of the mixture must be raised sufficiently to the ***ignition point*** before the reaction will take place. The ignition point varies with the type of fuel and the fuel:air ratio. Ignition of the fuel and air is a further function of the burner and is usually achieved by an electric spark, pilot flame or manually lighted torch.

A1.5 Stability

A flame front moves through a fuel/air mixture at a given speed dependent on the fuel and fuel:air ratio. In a stable combustion reaction, the flame front will appear to be stationary because the flame is moving towards the burner at the same speed as the fuel/air mixture emerges from the burner. If the mixture speed is too great, the flame will ***lift off*** the burner; too little and the flame will flash back into the burner body. Achieving a stable flame is another key function of the burner. Most burners incorporate some form of diffuser plate or swirler that recirculates the fuel/air mixture around the root of the flame and maintains ignition.

A1.6 Exhaust Gases and Losses

Exhaust gases leave the furnace by a flue or stack. These exhaust gases contain the following: products of combustion, mainly carbon dioxide and water vapour; any excess air, mostly oxygen and nitrogen; secondary combustion products, including carbon monoxide, and oxides of sulphur (SO_x) and of nitrogen (NO_x).

These exhaust gases represent inefficiency in the combustion process. Some losses are inevitable, but can be minimised by use of a correctly set-up combustion system. Flue gas losses are composed of three elements: dry, or sensible, flue gas losses are the losses due to the heat contained in the dry gases leaving the furnace; wet, or latent, flue gas losses are losses due to the latent heat contained in the water vapour leaving the furnace; unburned fuel losses represent the energy value of any unburned fuel or combustible intermediate compounds that leave the furnace without completing the combustion reaction. Measurement of the composition and temperature of the exhaust gases estimate all three losses. Subtracting these losses from 100% gives the ***inferred efficiency*** of the combustion process. This, together with measurement or estimation of the losses from the furnace body by ***conduction, convection*** and radiation, gives the inferred efficiency of the furnace system as a whole. Further details on the method of assessment of combustion efficiency are given in Appendix 2.

A1.7 Combustion Air Supply

In the simplest burners, the fuel and combustion air meet either within the body of the burner or at the nozzle. The air supply may be either at atmospheric pressure or pressurised by a fan or blower. Most burners used in industrial furnace applications incorporate some form of pressurisation of the combustion air and are known as forced draught burners.

In order to help the combustion reactions reach completion, a portion of the combustion air may be introduced to the flame after the burner nozzle. This is known as staged combustion, and the extra air is termed secondary combustion air. Some burner or furnace designs may incorporate features to introduce still more air (tertiary combustion air) in order to ensure complete burnout of fuels that are particularly difficult to burn, or to promote particular chemical reactions to reduce pollution. Air staging techniques are used by burner designers to reduce emissions of NO_x in particular. Secondary and tertiary air are introduced through diffusers, swirlers, or registers, the design of which may be used to influence the resulting flame shape.

APPENDIX 2

HOW TO ASSESS THE EFFICIENCY OF THE COMBUSTION PROCESS

The need for optimum combustion efficiency is an ongoing requirement. However, many furnace operators often may not appreciate the need for continual checking and adjustment under routine maintenance procedures. The main factors to consider are:

- the fuel:air ratio;
- air inleakage to the furnace.

Each percentage of oxygen above the optimum in the flue gases results in a 1 to 1.5% increase in energy consumption.

Burners are usually set up for optimum practical efficiency at commissioning. However, the efficiency may rapidly deteriorate with time, due to control drift or incorrect re-adjustment following disassembly. Fortunately, combustion efficiency testing is easy to carry out with portable instruments that can be purchased or hired, and will give a rapid return on costs through reduced fuel consumption.

The ideal combustion condition is stoichiometric, i.e. the fuel and air are present in the exact proportions necessary for complete chemical reaction. However, in practice, poor mixing of fuel and air means that some excess air is required to ensure that complete burnout occurs; otherwise, smoke, carbon monoxide, and other intermediate combustion compounds may be formed. The practical lower limit for oxygen in dry flue gases is around 2 to 3%, equivalent to 10 to 15% excess air, depending on the fuel used. Metallurgical considerations, e.g. the avoidance of scaling or oxidation of the stock, may dictate slight variations in the levels for certain types of furnace.

Worked Example

A gas-fired furnace is tested and found to have a flue gas oxygen level of 6% and a flue gas temperature of 500°C. Calculations show an excess air level of about 35% and, hence, an exhaust gas loss of 34.9%. Adjustments to the burner reduce the flue gas oxygen level to 3% (equivalent to 15% excess air) which, at the same flue gas temperature, represents a loss of only 31.5%. The reduction in losses achieved by adjustment of the fuel:air ratio is thus 9.7%. This would be worth over £4,800 per year on a furnace with an annual energy cost of £50,000.

Testing of furnaces to determine combustion efficiency involves sampling exhaust gases from the furnace flue using a combustion gas analyser. Care should be taken to ensure that the sample point will give a representative sample of the flue gases; it is worth carrying out several traverses of the flue to ensure an accurate mean value. Combustion analysis equipment ranges from simple, chemical absorption kits for the measurement of O_2, CO_2 (or both), to sophisticated electronic analysers capable of measuring CO, NO, NO_2, SO_2, and SO_3, as well as O_2, CO_2 and temperature. Chemical kits will require a separate means of ***temperature measurement,*** and manual calculation of efficiency using either a nomogram or standard formulae, whereas most electronic analysers will calculate efficiency automatically, using stored constants. Electronic analysers are quicker and easier to use but are technically more complex than simple chemical analysers and may require periodic recalibration. The fluids in chemical kits will require periodic replacement.

A high waste gas temperature may indicate poor heat transfer to the stock, and the cause should be investigated and rectified. A low flue gas temperature does not necessarily indicate good heat transfer; air inleakage may be diluting and cooling the flue gases, thus considerably reducing the efficiency of the furnace. If the heat transfer is optimised and the waste gas temperature is still high, then there may be an opportunity for waste heat recovery. This is covered elsewhere in this Guide and in considerably greater depth in Good Practice Guide 13, *Waste heat recovery from high temperature gas streams.*

An electronic analyser costs from as little as £500 for a basic model, up to around £3,000 for a fully featured model. To hire a mid-range analyser from a commercial instrument hire company would cost in the region of £100 to £150 per week. A chemical absorption kit costs around £750. Details of combustion analysis equipment suppliers and hire companies can be found in Section 8.7.

Once the existing level of performance has been established, it should be a simple matter to make any adjustments to the burner to correct the fuel:air ratio as required. Air inleakage to the furnace is another cause of poor performance and should be rectified. Furnace testing is outside the remit of this Guide. Further information on the subject can be found in a companion Guide - Good Practice Guide 253, *Choosing, using and modifying furnaces.*

APPENDIX 3

HEAT TRANSFER

A3.1 Principles of Heat Transfer

Heat transfer is defined as energy in transit as a result of a difference in temperature. There are three main mechanisms of heat transfer: ***conduction, convection,*** and thermal ***radiation.***

In the case of conduction, heat energy is transferred on a molecular scale, with no large-scale movement of matter. Convection occurs when there is a temperature difference between a fluid and a solid boundary. It is a combination of both heat flow and fluid flow (mass transfer). Two cases of convection occur: forced ***convection*** when the flow of fluid is caused by some external means, e.g. the action of a fan or pump; natural ***convection*** when the flow is simply a result of differences in buoyancy with the fluid. Radiation does not require the existence of an intervening medium. It occurs as a result of the energy, in the form of electromagnetic waves, emitted by all matter. The quantity of energy transferred is dependent on the temperature and emissivity of the emitting body, which may be a solid, a liquid or, in the case of radiative heat transfer from flames, a gas.

In practice, all three mechanisms operate simultaneously; however, for the purposes of heat transfer between the flame and furnace stock, convection and radiation are the main mechanisms.

A3.2 Choice of Heat Transfer Method

Radiation has two main advantages: it has high intensity or power, i.e. high heat input rates can be readily achieved to suit high-speed production processes; it can be easily spread over a wide area. Disadvantages are: it travels only in straight lines, with the result that some stock may not be adequately heated; it cannot be readily controlled. Stock may continue to be heated by the radiation from the furnace walls and ceiling, even after the flame has been turned off.

Convection can be more readily directed around the interior of a furnace and can penetrate throughout the load, thus ensuring even heating of the stock. Convective heating is beneficial in treatments requiring an element of mass transfer, e.g. drying operations.

The heat transfer method chosen depends largely on the application: radiation tends to be more effective in melting of metal and glass, and holding of the molten metal or glass, and for forging, galvanising and reheating processes; convection methods tend to be used for processes such as drying, normalising, stress-relieving, and heating of densely-packed loads, or for high-velocity flame heating.

A3.3 Influence of Flame Characteristics on Heat Transfer

The shape and characteristics of the flame have a strong influence on the heat transfer between the flame and the stock, and burner design and choice of fuel can be manipulated to achieve the desired effect. The design of the burner determines the relative velocities of the fuel and air streams, and hence the flame length and shape. Good mixing, as a result of high turbulence and velocity, produces a short, bushy flame, whereas poor or delayed mixing will produce a longer, slender flame. A turbulent, high-velocity flame will churn up the atmosphere within the furnace and promote high rates of convective heat transfer, whereas a long, slender flame will have a higher radiative heat transfer component.

Fuel choice also has a strong bearing on the radiative heat transfer characteristics. Oil firing produces flames that are yellower and more luminous (with relatively better radiation characteristics) than a well-mixed natural-gas flame, which tends to be bluer and less luminous. A poorly mixed or delayed mix natural-gas flame may, however, give a yellower, more luminous flame due to the incandescence of carbon particles in the flame. These are produced by pyrolysis of the hydrocarbon compounds in the gas.

APPENDIX 4

PRINCIPLES OF NO_x FORMATION AND METHODS OF REDUCTION AND CONTROL

A4.1 NO_x Formation

The term NO_x refers to the combined oxides of nitrogen, principally nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O). NO is formed during the combustion of fossil fuels. A small part of it is oxidised to NO_2 in the flame, but most of this oxidation occurs after the combustion products are exhausted into the atmosphere. The formation of NO in flames involves three routes:

- the ‘thermal’ mechanism;
- the ‘prompt’ mechanism;
- the ‘fuel’ mechanism.

The thermal and prompt routes describe the oxidation of molecular nitrogen in air, while the fuel route describes the oxidation of nitrogen-containing compounds. This third route can be significant in the combustion of coal and oils, but negligible in natural-gas combustion. Thermal NO is normally more significant than prompt NO, with the amount of prompt NO formation being typically about an order of magnitude less than thermal NO.

It is generally believed that thermal NOx formation is highly dependent on temperature, linearly dependent on oxygen atom concentration, and independent of fuel type. Figs 35 and 36 illustrate the effects of temperature and oxygen, respectively, on NO_x formation for a typical burner set up.

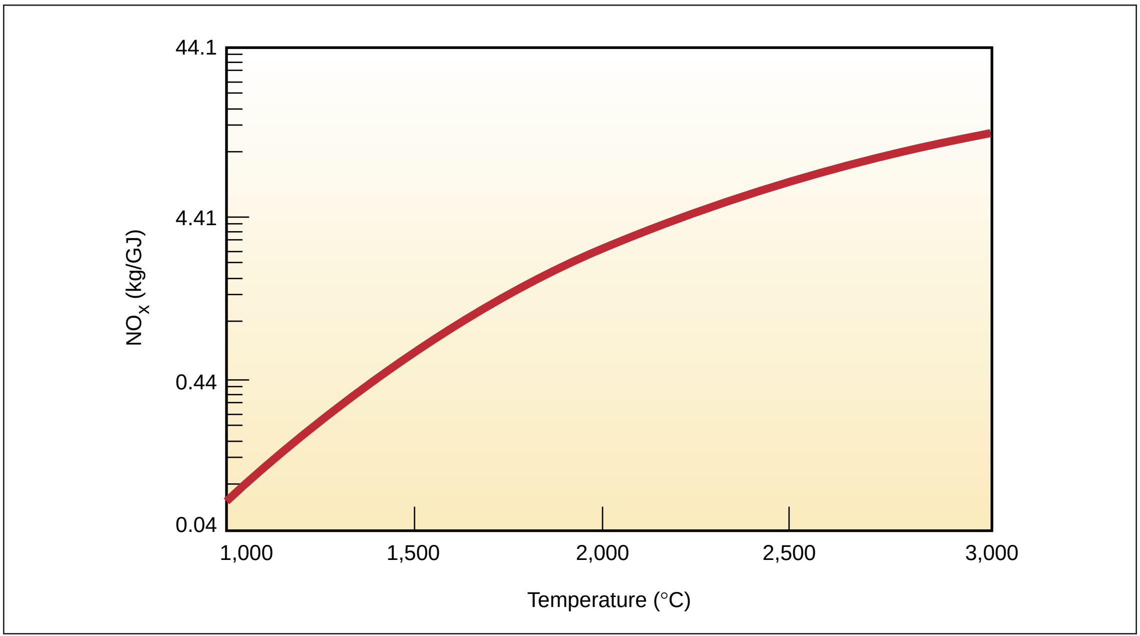


Fig 35 The effects of temperature on NO_x formation

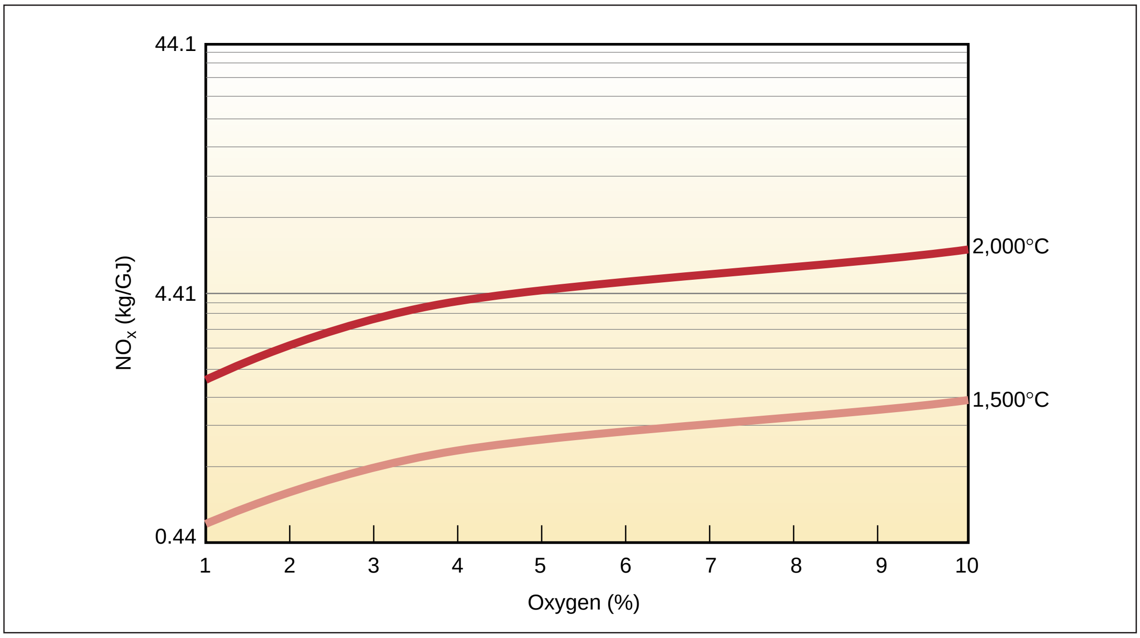


Fig 36 The effects of oxygen levels on NO_x formation

The prompt NO mechanism, which involves reactions of fuel-derived radicals with N_2, occurs under fuel-rich conditions, with short residence time and low temperature. In certain circumstances a reaction occurs which can destroy NO. This phenomenon is utilised in fuel staging or reburning NO_x reduction techniques. Most of the fuel is burned in a primary zone with excess oxygen; the remaining fuel is injected downstream to create a secondary fuel-rich - or 'reburn' - zone where the NO is reduced to N_2. Tertiary air is added further downstream to complete the combustion.

A4.2 NO_x Reduction and Control

There are two approaches to reducing the discharge of NO_x formation from a combustion process: the first, and the cheapest, method is to minimise the formation of NO_x in the flame by paying careful attention to combustion parameters. The second method is to allow the NO_x to form and then to try and reduce emissions by treatment of the flue gases downstream.

From the point of view of a furnace operator, preventing the formation of NO_x is largely a matter of selecting a low-NO_x burner design from a manufacturer. This will inevitably cost slightly more than a conventional burner, but, when considered in the context of a complete reburnering exercise or the construction of a new furnace, the additional costs are not likely to be significant.

Burner manufacturers use staged combustion techniques and/or flue gas recirculation to achieve acceptable NO_x formation levels. Another approach is to reduce or exclude molecular nitrogen from the flame by using oxy-fuel firing techniques as discussed earlier in this Guide. This is effective in reducing NO_x levels on a weight basis, although they may appear to be higher on a volumetric basis due to the reduction in flue gas volume. Some NO_x will inevitably be formed, as it is practically impossible to exclude atmospheric air from the furnace space.

Downstream control is likely to be considerably more complex and hence more expensive. The chief methods employed are:

- Selective Catalytic Reduction (SCR): This technique uses injection of ammonia over a catalyst bed to promote a reaction that reduces the NO_x to molecular nitrogen. The process can achieve high reduction rates of 80 - 90% or more, but has high capital and operating costs. There may be problems with catalyst poisoning and fly ash plugging (blockages in the catalyst caused by solid particles in the gas stream), so this technique is best suited to clean applications. The technique is currently undergoing further development, which may lead to more widespread application in the future.

- Selective Non-Catalytic Reduction (SNCR): This process operates on similar principles to SCR and achieves NO_x reductions of 60 - 90%. The process requires higher temperatures than SCR but does not involve the additional expense of a catalyst.

For further information on NO_x formation and control, see General Information Report 45, *NO_x reduction technology for steel reheating and heat treatment furnaces*.

APPENDIX 5

OVERVIEW OF RELEVANT ENVIRONMENTAL LEGISLATION

Plant size MW_{th} net heat input		**< 20 MW**		**> 20 MW < 50 MW Non-aggregated plant**			**> 50 MW < 500 MW Aggregated plant from 3 MW min.**		**> 500 MW Aggregated plant**	
Legislation/guidance		Clean Air Act 1993		EPA 1990 Part 'B' Processes Secretary of State's Guidance Notes PG 1/3 (95)			EPA 1990 Part 'A' Processes Chief Inspector's Guidance Notes S2 1.01 (95)			
Controlling Authority		Local Authority		Local Authority			Environment Agency			
Date of effect	Existing plant	27/5/93		1/10/97			New limit 01/04/2001 Existing limit 01/04/1995			
	New plant	27/5/93		1/8/95			01/07/1987			
Fuel type		Gas	Liquid	Gas	Liquid					
					Fuels (Class C, C2, D)	Fuels Class (E,F,G,H)	Gas	Liquid	Gas	Liquid
	Particulates (mg/nm^3)	–	300 - 400 (smoke limits)	5	100 (150 existing)	150	5	50	5	50
Emissions limits	NO_x (mg (NO_2) $/nm^3$)	—	n/a	140 (200 existing)	200 (300 existing)	450 (600 existing)	350	450 (650 existing)	350	450
	SO_x (mg/nm^3)	—	Some inner-city local controls	35	350	3,000 (= 1.76 % S)	5	1,700 (= 1.0 % S)	5	400 (= 0.23 % S)

Table courtesy of Saacke Ltd.
Legislation as at July 1998.

Please note that the information contained in this table is subject to change and should not be taken as definitive. The original documentation should be consulted for confirmation.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

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General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.